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(54) **POWER GENERATION AND BATTERY MANAGEMENT SYSTEMS**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 11/560,160, filed on Nov. 15, 2006, now Pat. No. 7,797,958.

(51) **Int. Cl.**
H01M 10/46 (2006.01)

(52) **U.S. Cl.** **320/103**; 320/104

(58) **Field of Classification Search** 320/103, 320/104, 107, 112, 114, 116, 132, 138
See application file for complete search history.

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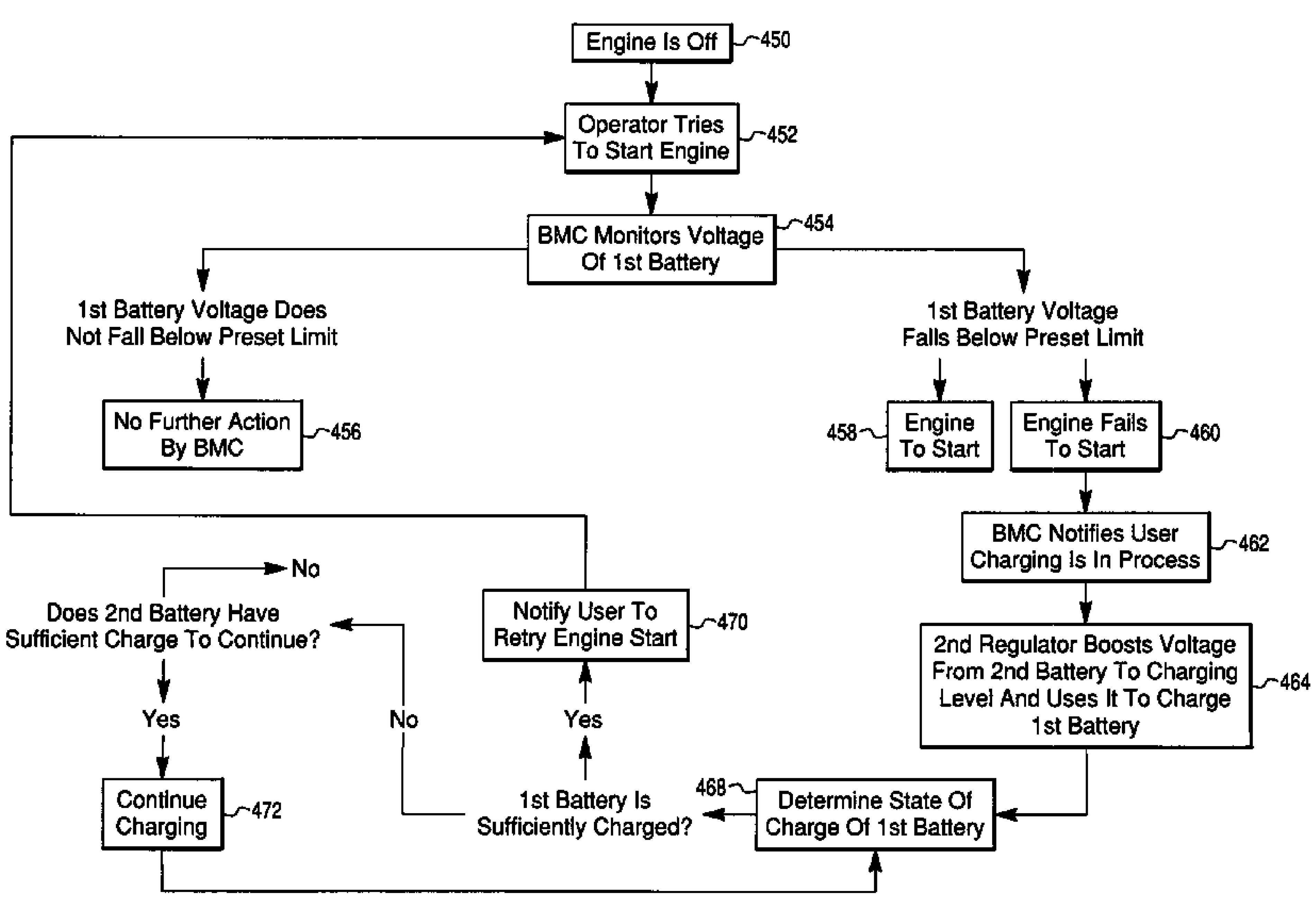
(74) *Attorney, Agent, or Firm* — Foley & Lardner LLP

(57) **ABSTRACT**

The disclosed power system may comprise first and second batteries; an electrical power generator; an electrical load powered by at least one of the first battery, the second battery or the electrical power generator; a converter; and a battery management controller. The converter is connected to both the first and second batteries and configured to operate in a neutral mode, a first battery charging mode, or a second battery charging mode. The converter is configured to create a voltage difference between the first and second batteries in the charging modes. The battery management controller is configured to monitor the voltage of the first battery and the voltage of the second battery and/or to monitor current flow to and from the first and second batteries. The controller controls operation of the converter to operate in the neutral mode, the first battery charging mode or the second battery charging mode.

22 Claims, 18 Drawing Sheets



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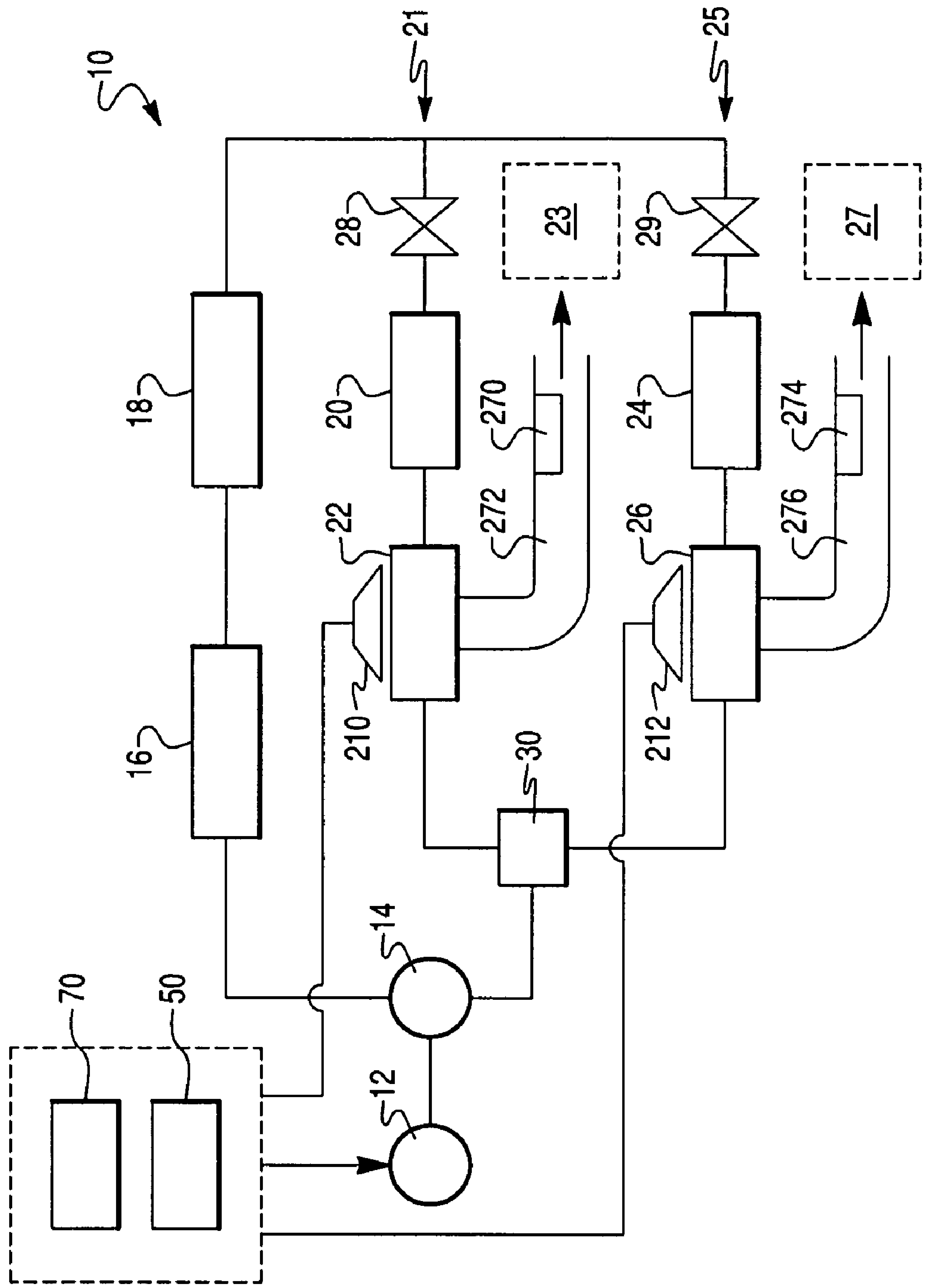
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28
23
29
27
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50
12

Fig. 1

Fig. 2

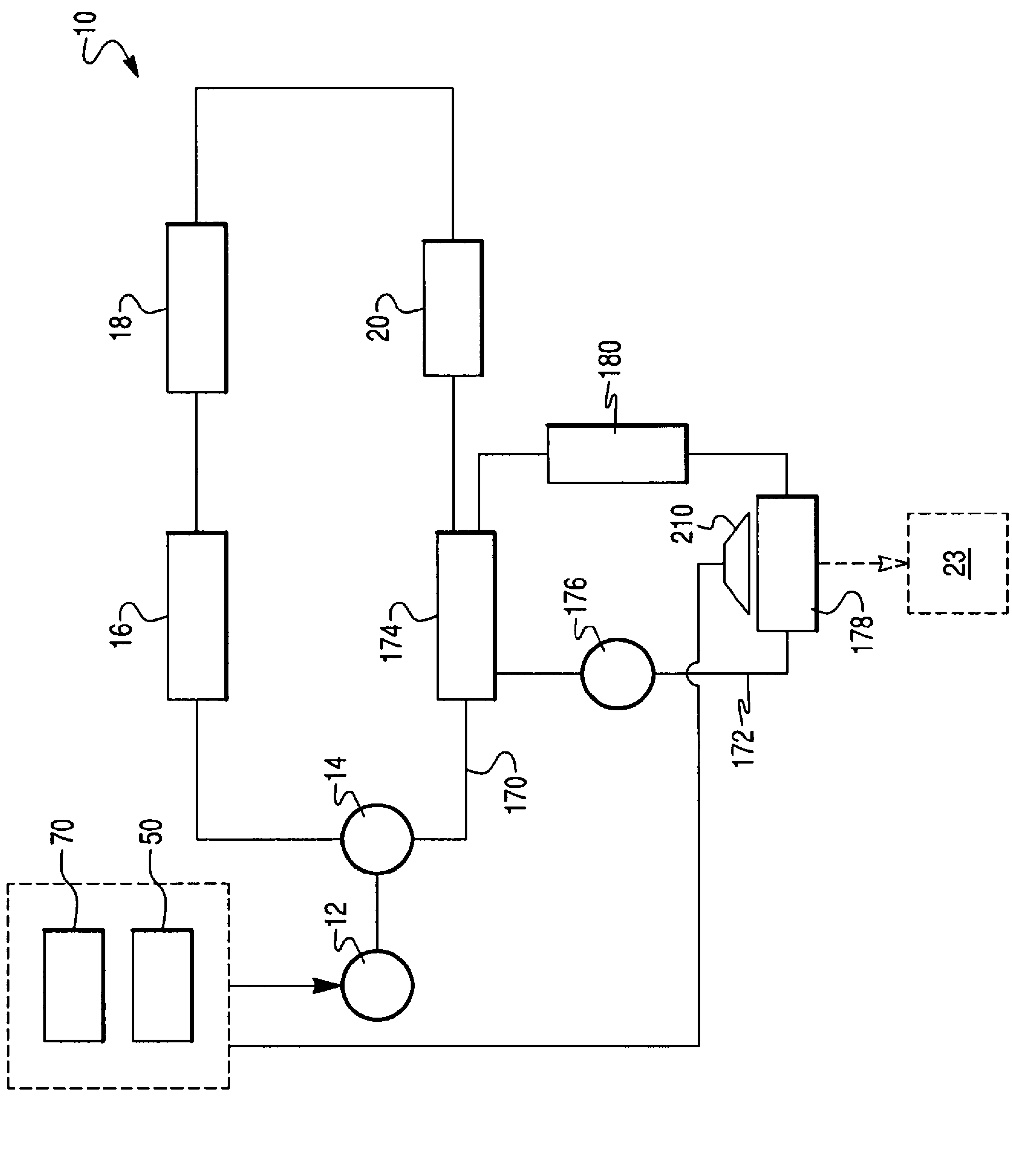


Fig. 3

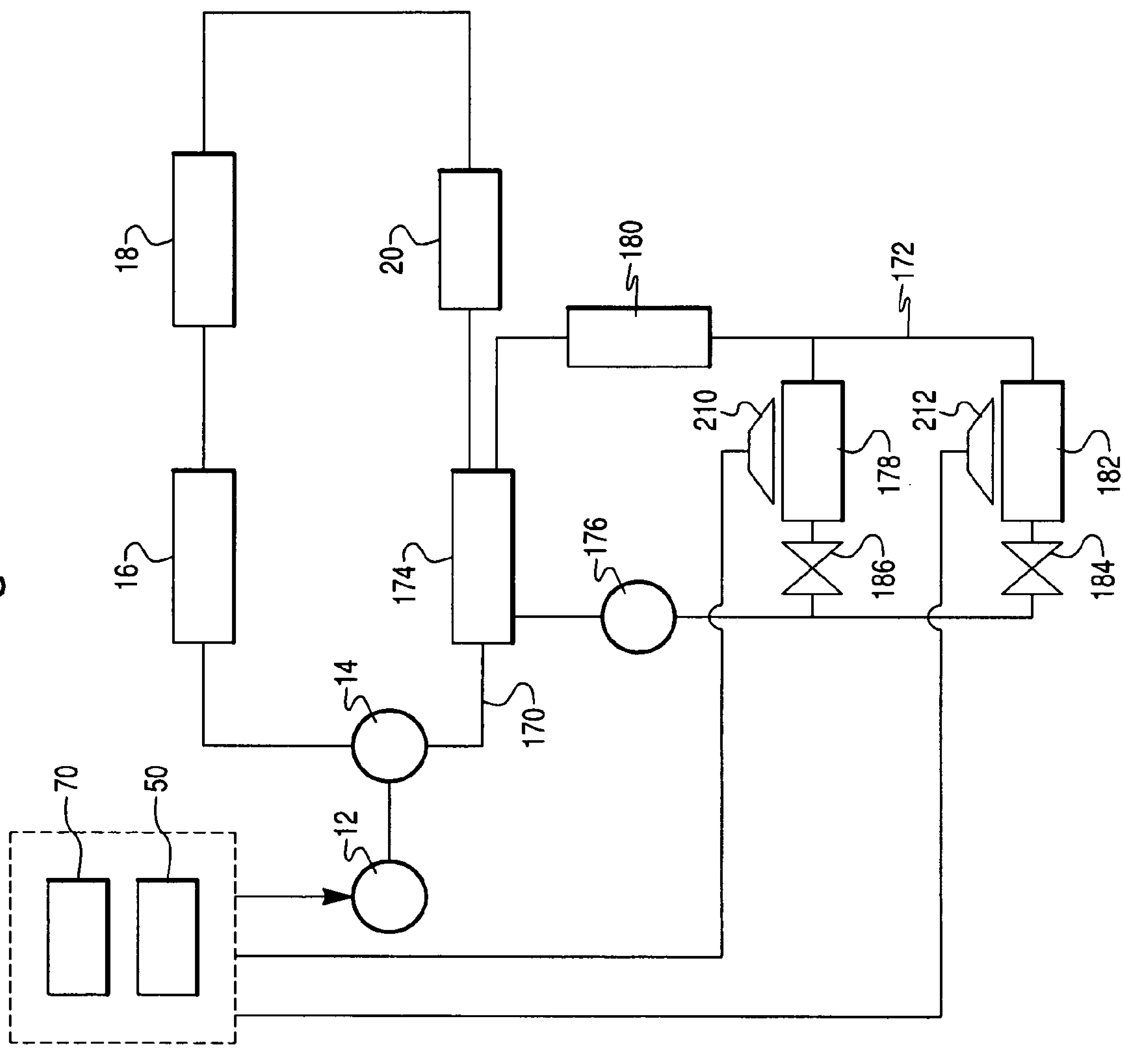
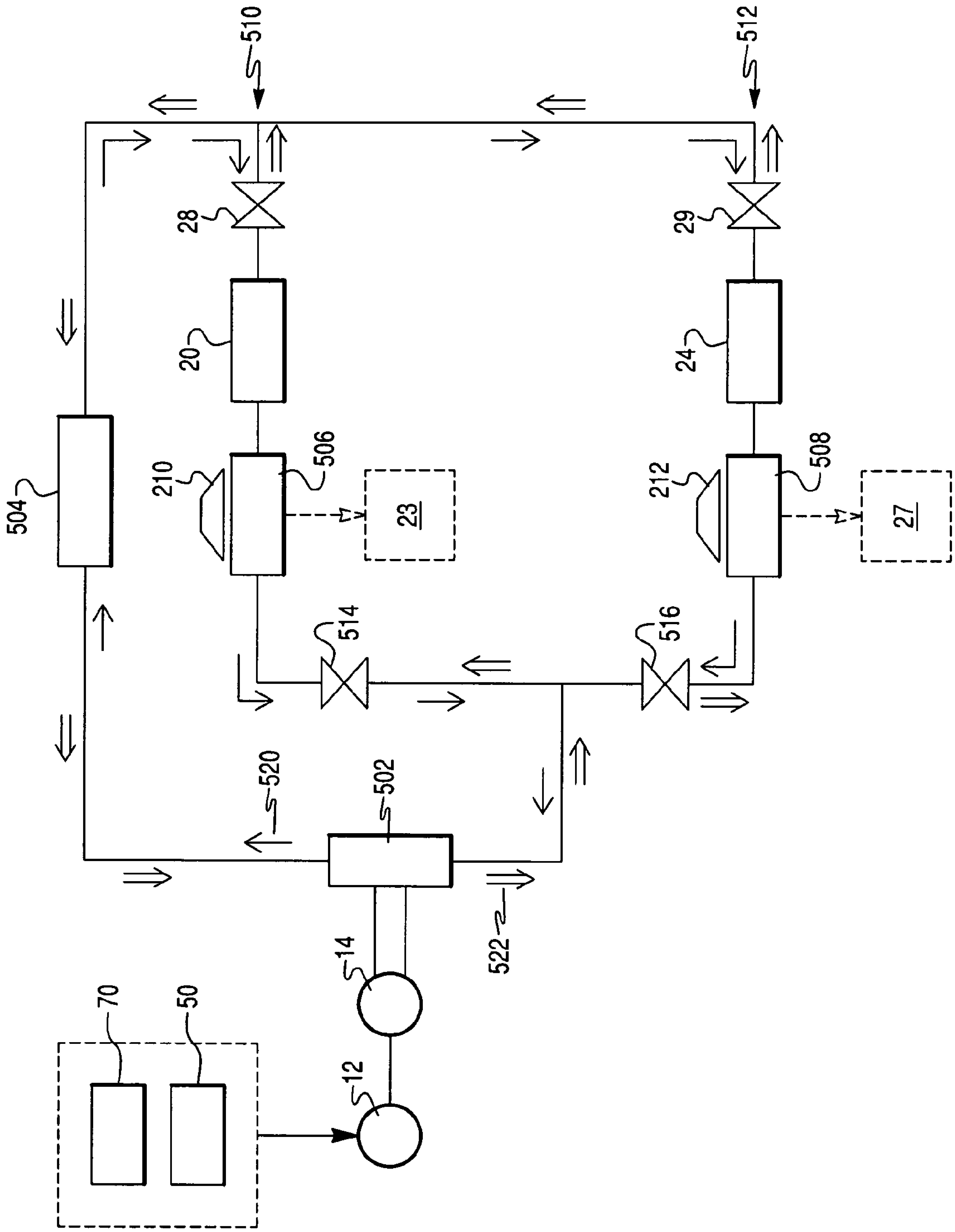


Fig. 4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512
28
29
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504
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502
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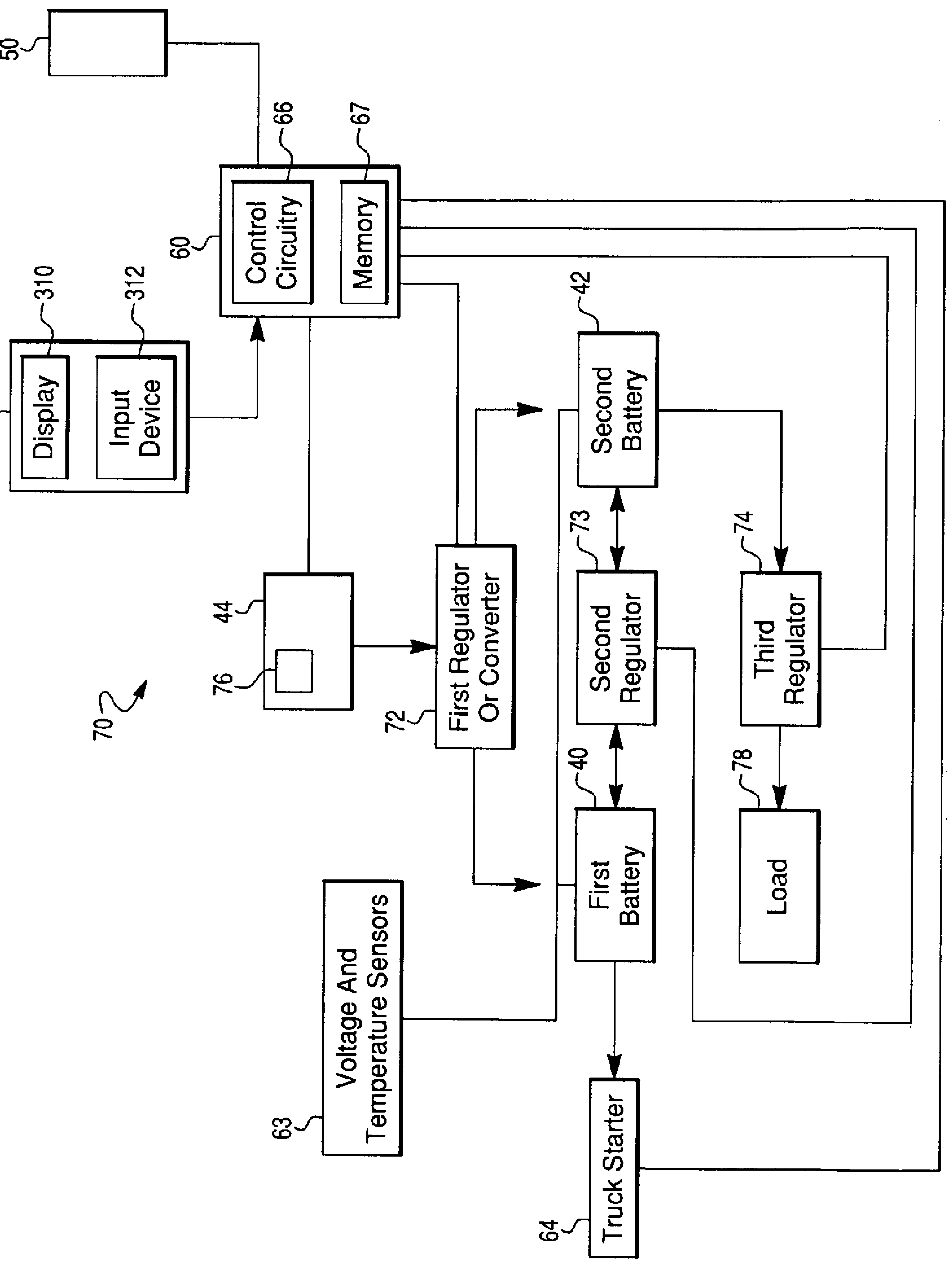
70
50

Fig. 5


50
51
Display
310
Input Device
312
60
Control Circuitry
66
Memory
67
44
76
70
First Regulator Or Converter
72
Second Battery
42
Second Regulator
73
Third Regulator
74
First Battery
40
Load
78
Voltage And Temperature Sensors
63
Truck Starter
64

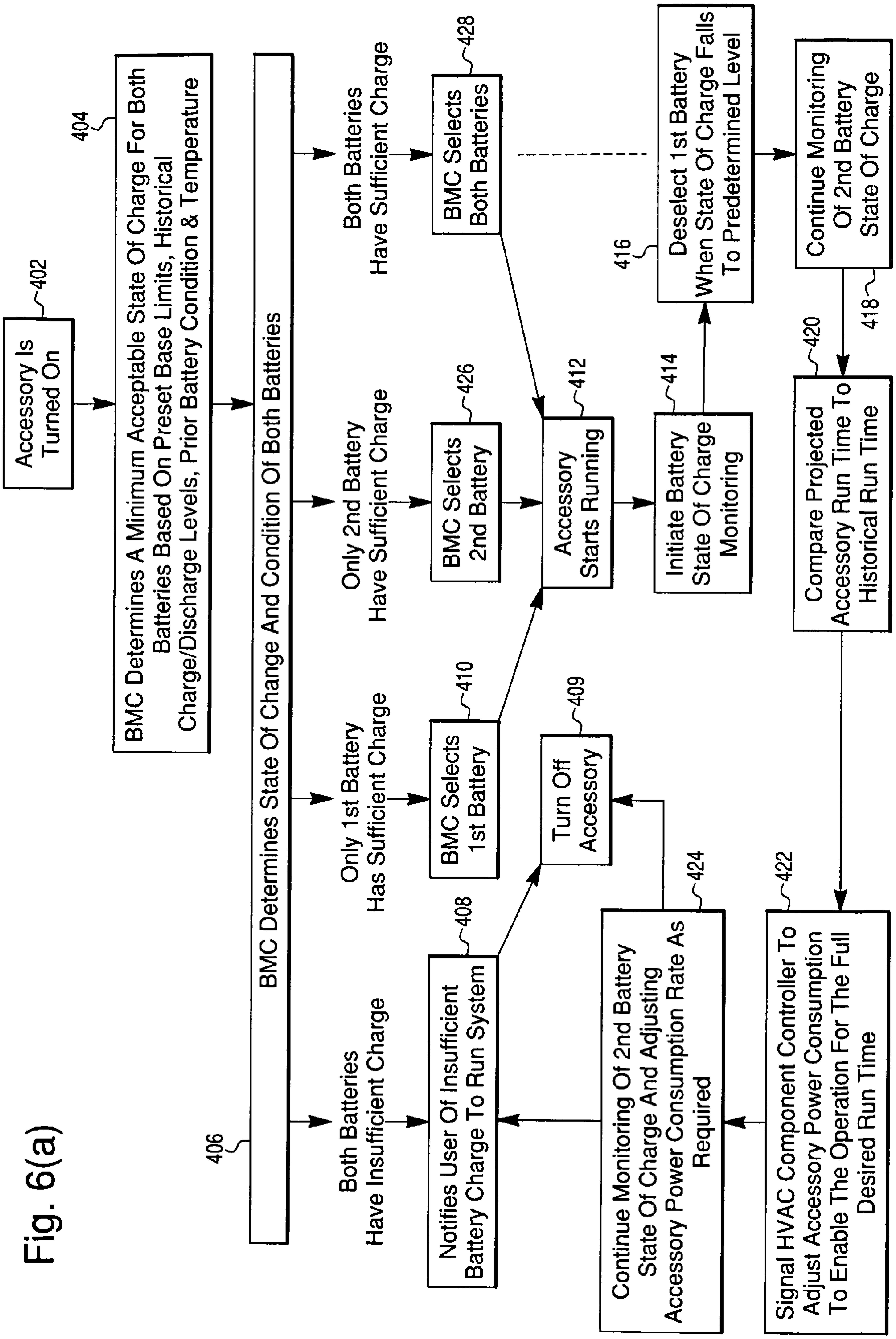

Accessory Is Turned On
402
BMC Determines A Minimum Acceptable State Of Charge For Both Batteries Based On Preset Base Limits, Historical Charge/Discharge Levels, Prior Battery Condition & Temperature
404
BMC Determines State Of Change And Condition Of Both Batteries
406
Both Batteries Have Insufficient Charge
Only 1st Battery Has Sufficient Charge
Only 2nd Battery Have Sufficient Charge
Both Batteries Have Sufficient Charge
Notifies User Of Insufficient Battery Charge To Run System
408
BMC Selects 1st Battery
410
BMC Selects 2nd Battery
426
BMC Selects Both Batteries
428
Turn Off Accessory
409
Accessory Starts Running
412
Initiate Battery State Of Charge Monitoring
414
Deselect 1st Battery When State Of Charge Falls To Predetermined Level
416
Continue Monitoring Of 2nd Battery State Of Charge
418
Compare Projected Accessory Run Time To Historical Run Time
420
Signal HVAC Component Controller To Adjust Accessory Power Consumption To Enable The Operation For The Full Desired Run Time
422
Continue Monitoring Of 2nd Battery State Of Charge And Adjusting Accessory Power Consumption Rate As Required
424

Fig. 6(a)

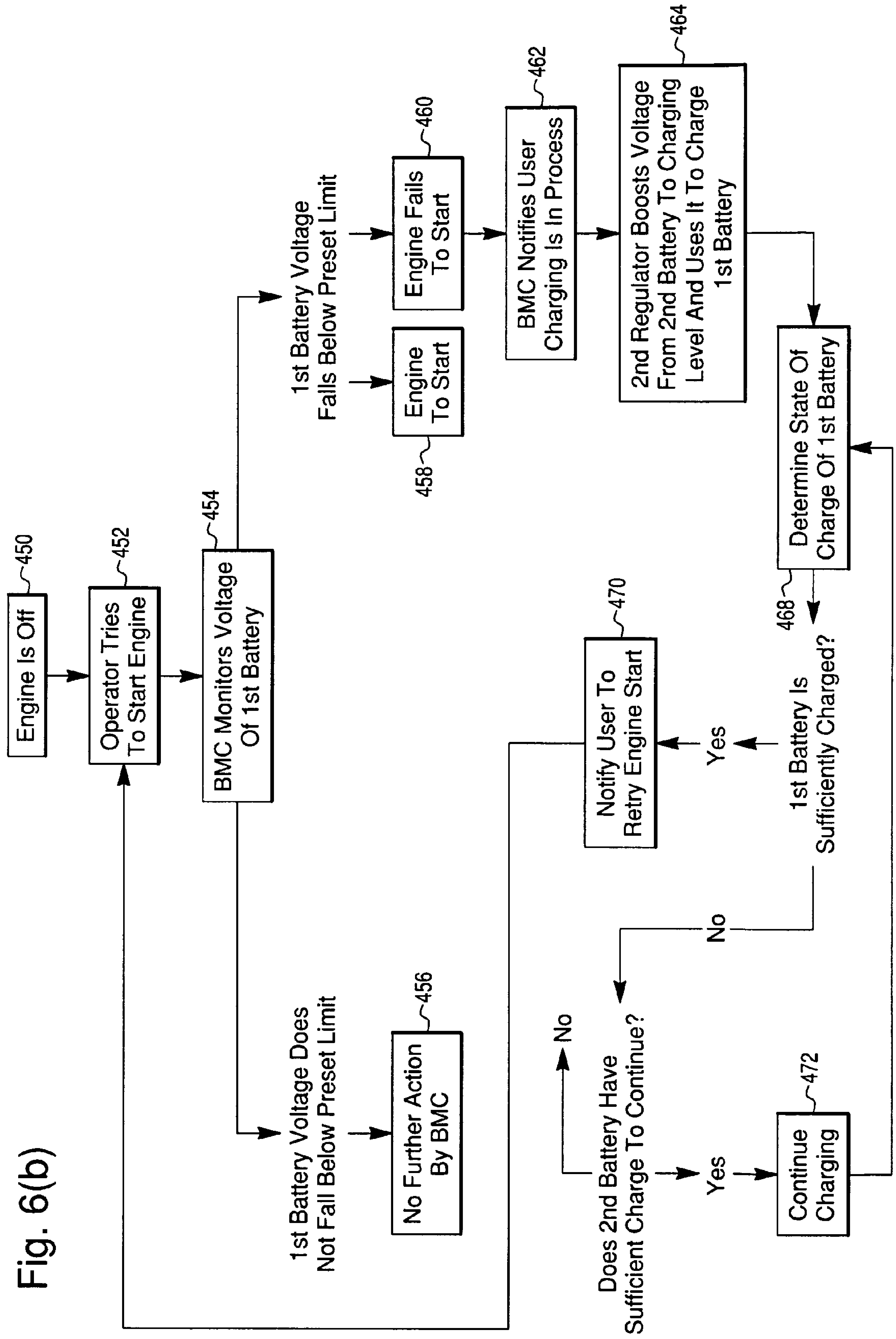

Engine Is Off
450
Operator Tries To Start Engine
452
BMC Monitors Voltage Of 1st Battery
454
1st Battery Voltage Falls Below Preset Limit
1st Battery Voltage Does Not Fall Below Preset Limit
No Further Action By BMC
456
Engine To Start
458
Engine Fails To Start
460
BMC Notifies User Charging Is In Process
462
2nd Regulator Boosts Voltage From 2nd Battery To Charging Level And Uses It To Charge 1st Battery
464
Determine State Of Charge Of 1st Battery
468
1st Battery Is Sufficiently Charged?
Yes
No
Notify User To Retry Engine Start
470
Does 2nd Battery Have Sufficient Charge To Continue?
Yes
No
Continue Charging
472

Fig. 6(b)

Fig. 6(c)

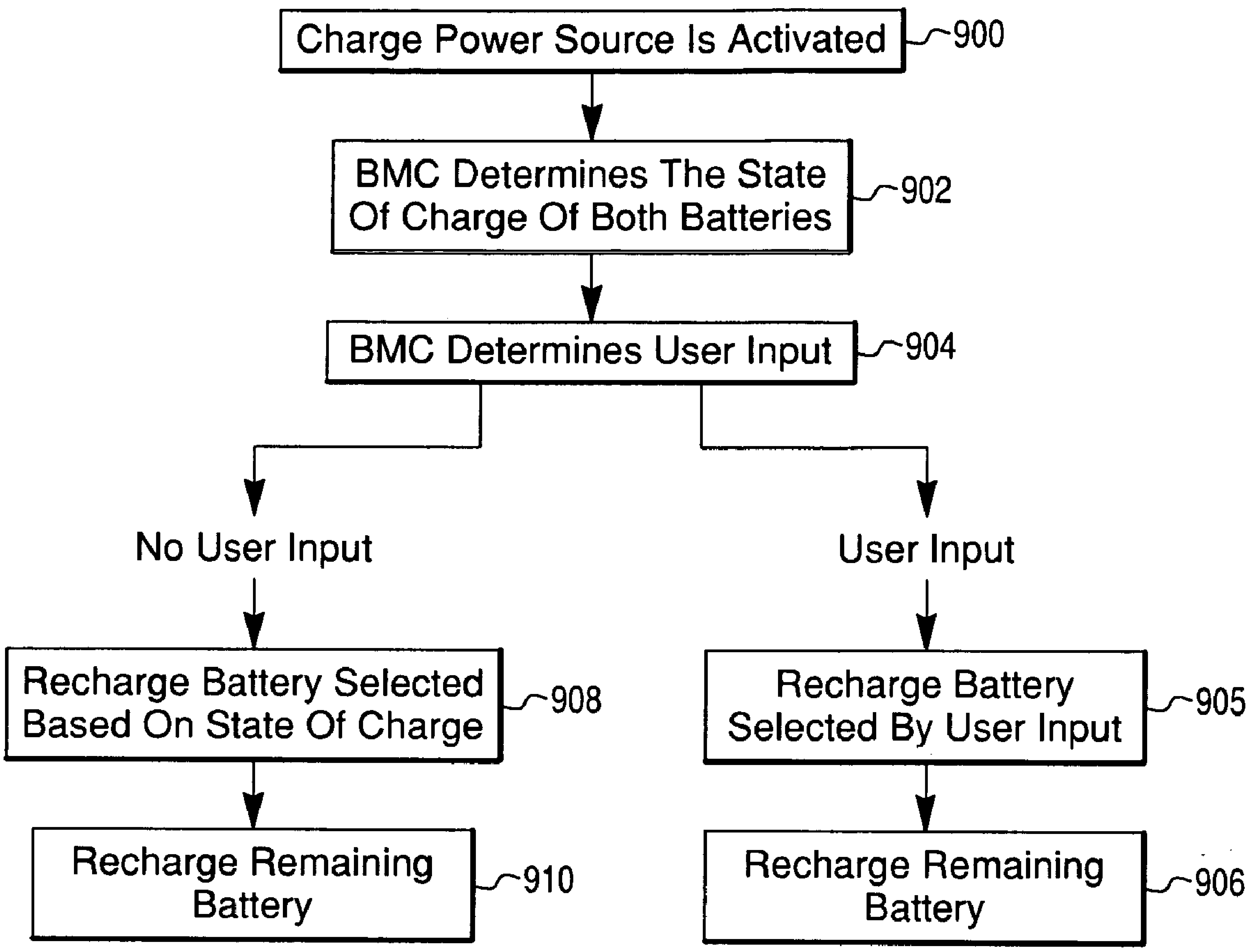

Charge Power Source Is Activated
900
BMC Determines The State Of Charge Of Both Batteries
902
BMC Determines User Input
904
No User Input
User Input
Recharge Battery Selected Based On State Of Charge
908
Recharge Battery Selected By User Input
905
Recharge Remaining Battery
910
Recharge Remaining Battery
906

Fig. 7

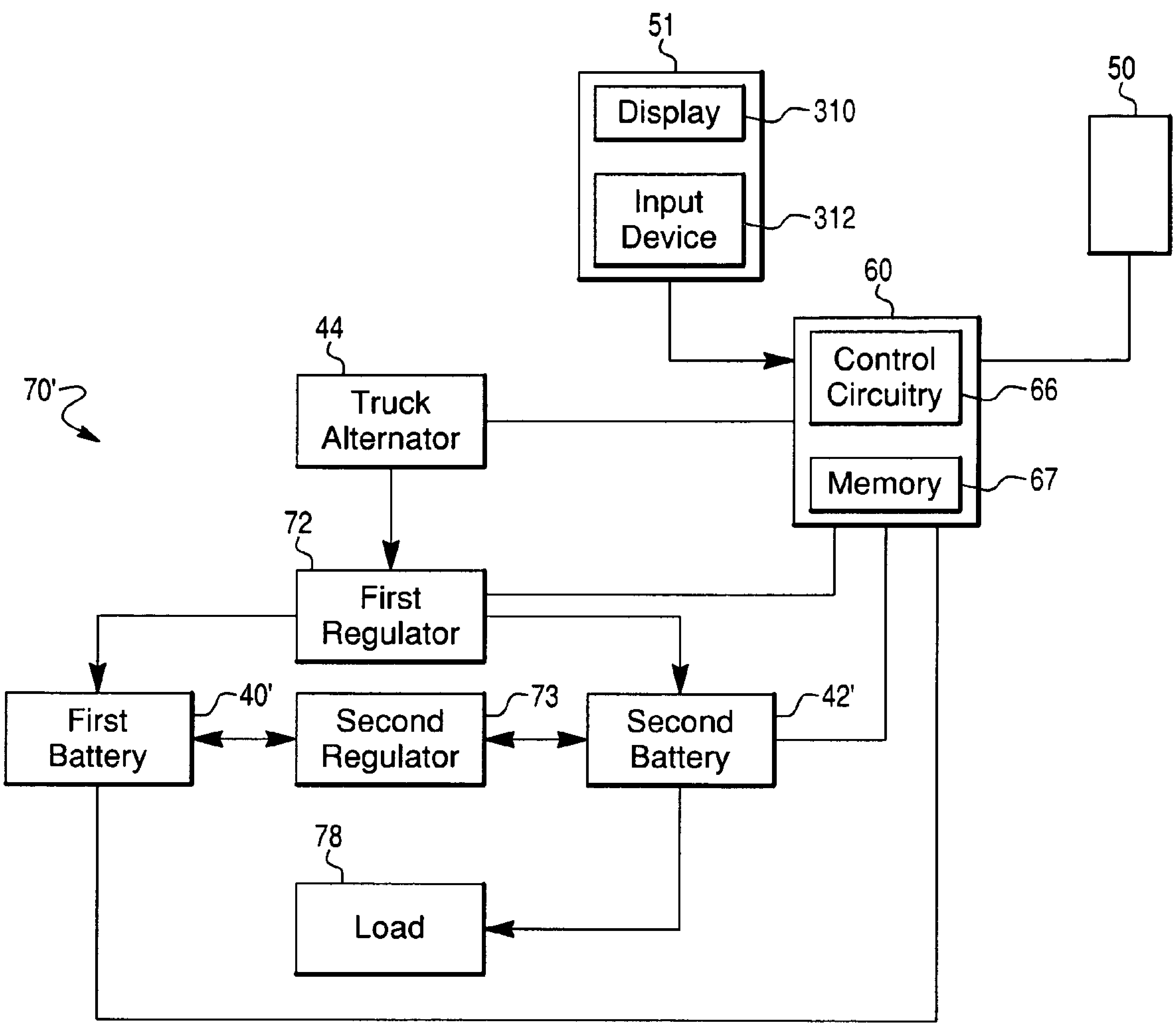

51
Display
310
Input
Device
312
50
60
Control
Circuitry
66
Memory
67
44
Truck
Alternator
70'
72
First
Regulator
First
Battery
40'
Second
Regulator
73
Second
Battery
42'
78
Load

Fig. 8

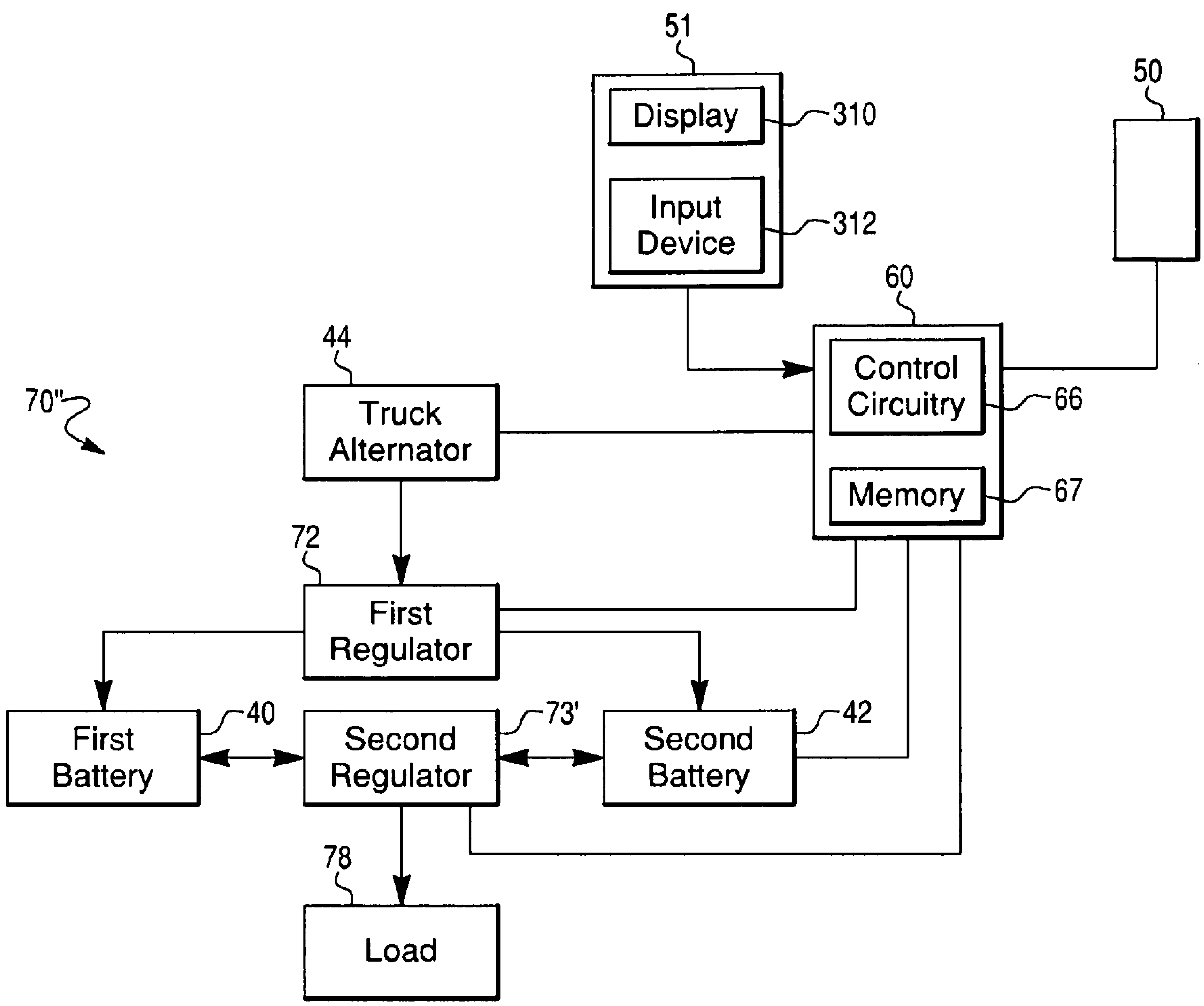

51
Display
310
Input Device
312
50
60
Control Circuitry
66
Memory
67
44
Truck Alternator
70"
72
First Regulator
First Battery
40
Second Regulator
73'
Second Battery
42
78
Load

Fig. 9

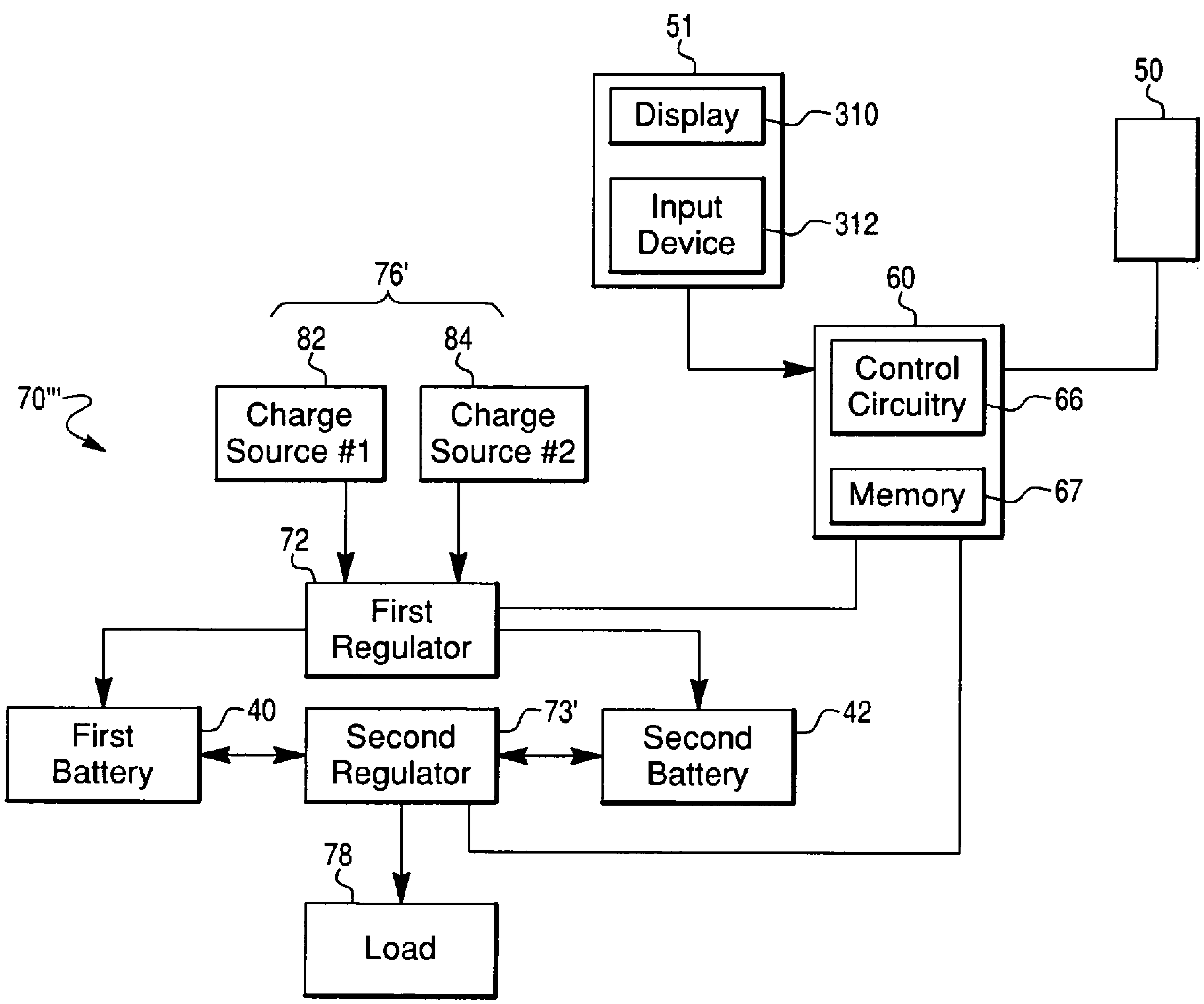

51
Display
310
Input
Device
312
50
60
Control
Circuitry
66
Memory
67
76'
82
84
70'''
Charge
Source #1
Charge
Source #2
72
First
Regulator
First
Battery
40
Second
Regulator
73'
Second
Battery
42
78
Load

Fig. 10

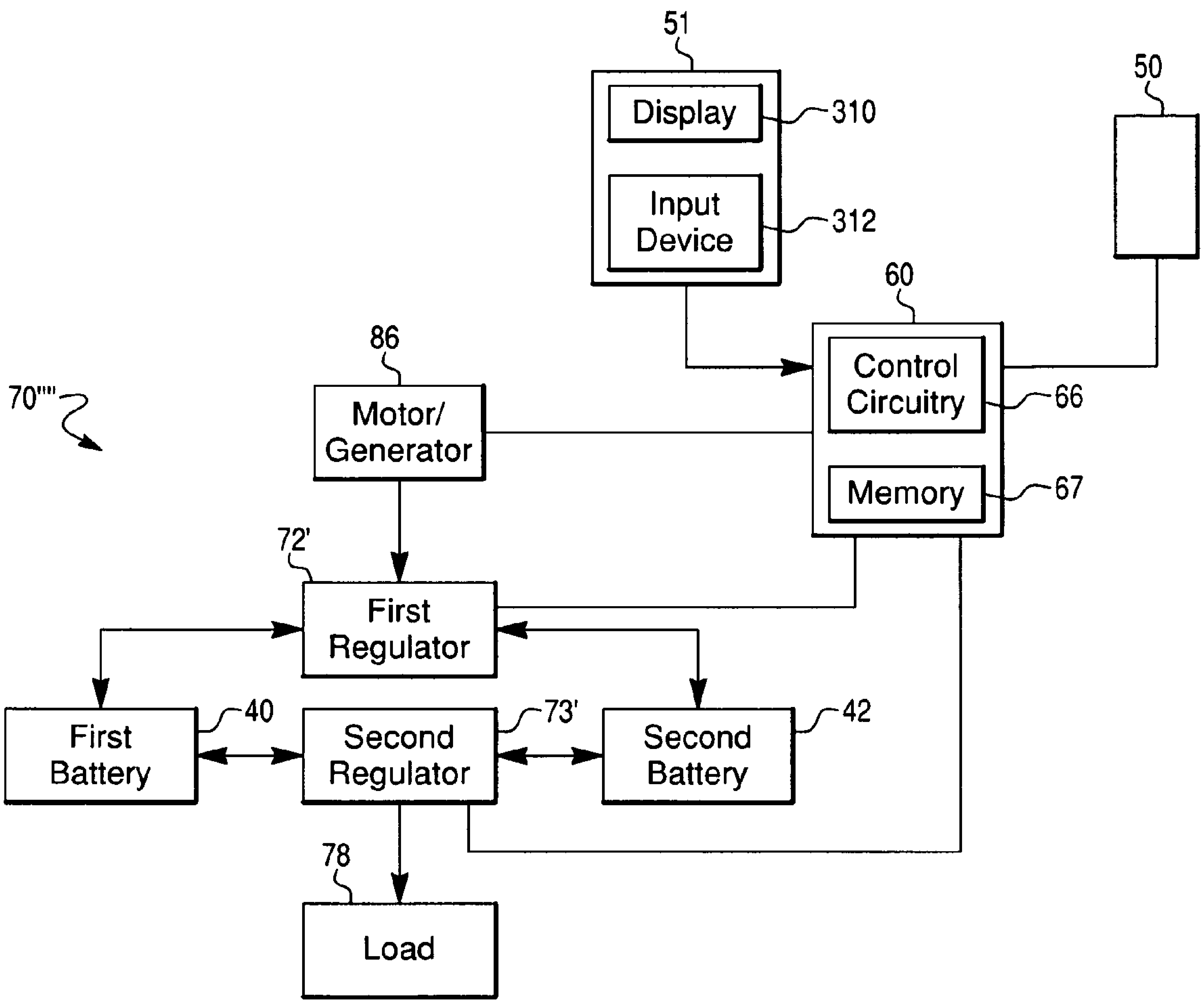
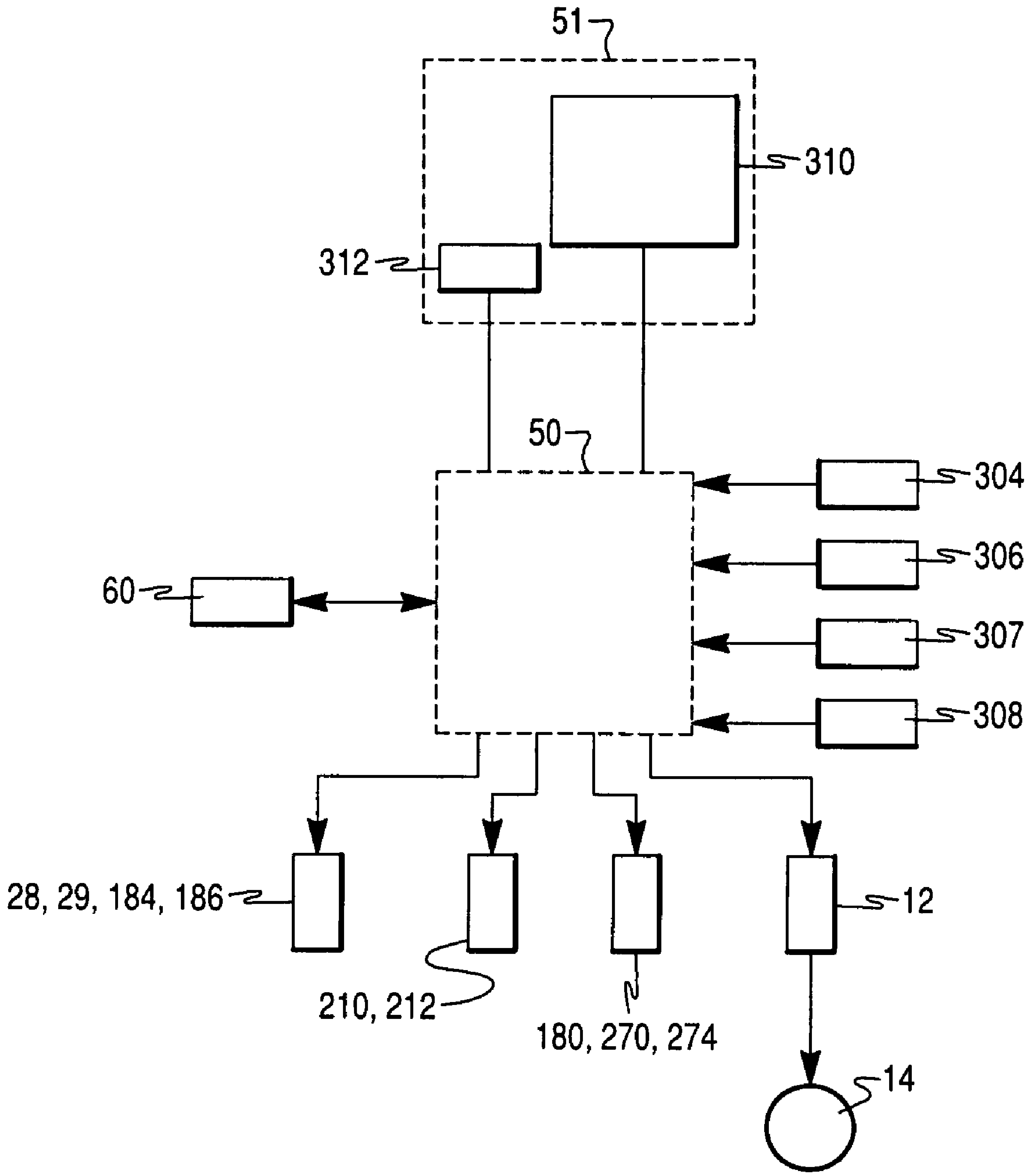

51
Display
310
Input Device
312
50
60
Control Circuitry
66
Memory
67
86
Motor/ Generator
70""
72'
First Regulator
First Battery
40
Second Regulator
73'
Second Battery
42
78
Load

Fig. 11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180, 270, 274
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14

Fig. 12

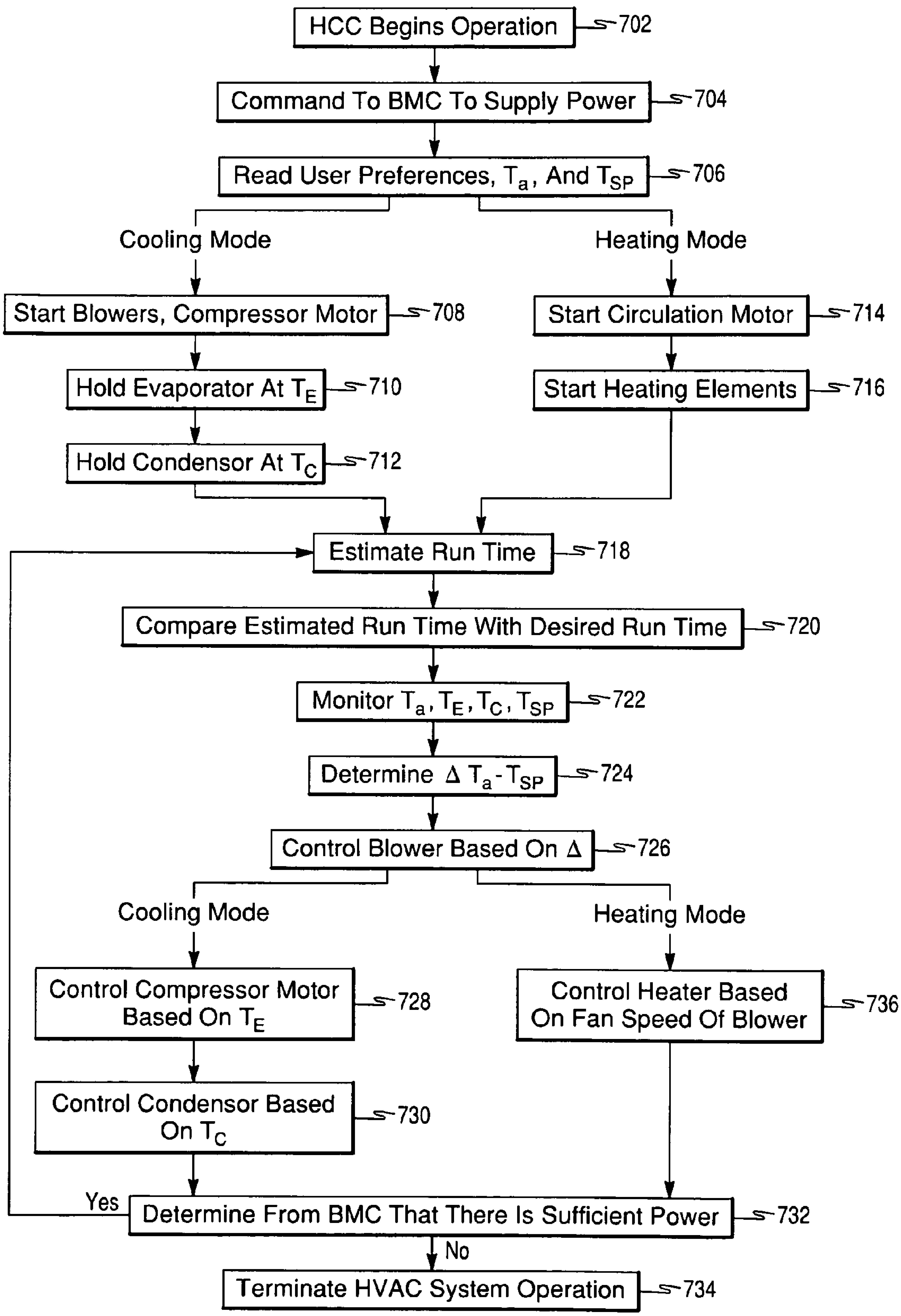
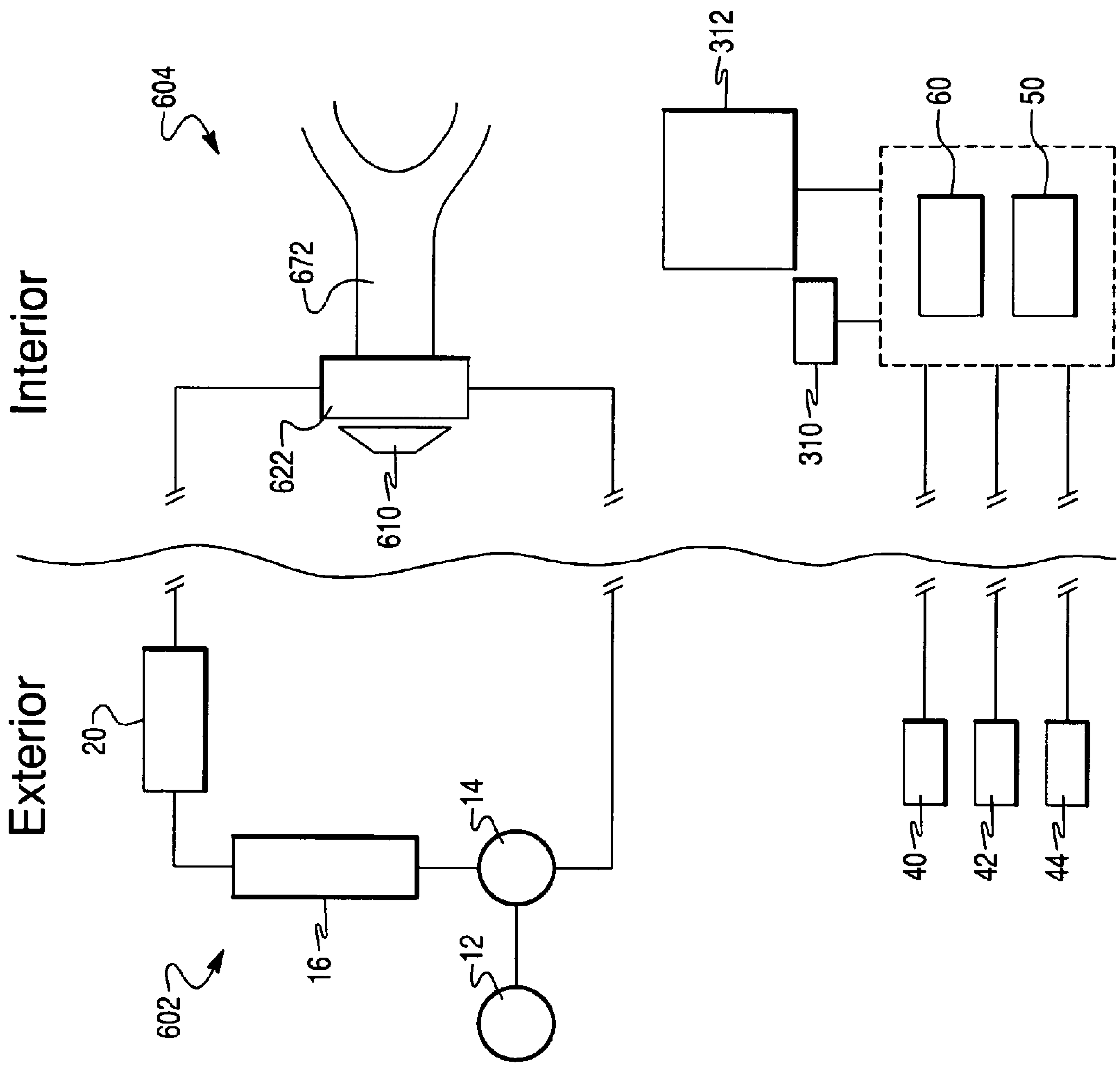

HCC Begins Operation
702
Command To BMC To Supply Power
704
Read User Preferences, T_a, And T_{SP}
706
Cooling Mode
Heating Mode
Start Blowers, Compressor Motor
708
Start Circulation Motor
714
Hold Evaporator At T_E
710
Start Heating Elements
716
Hold Condensor At T_C
712
Estimate Run Time
718
Compare Estimated Run Time With Desired Run Time
720
Monitor T_a, T_E, T_C, T_{SP}
722
Determine Δ T_a - T_{SP}
724
Control Blower Based On Δ
726
Cooling Mode
Heating Mode
Control Compressor Motor Based On T_E
728
Control Heater Based On Fan Speed Of Blower
736
Control Condensor Based On T_C
730
Yes
Determine From BMC That There Is Sufficient Power
732
No
Terminate HVAC System Operation
734

Fig. 13


Interior
Exterior
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672
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622
610
310
20
602
16
12
14
40
42
44

Fig. 14

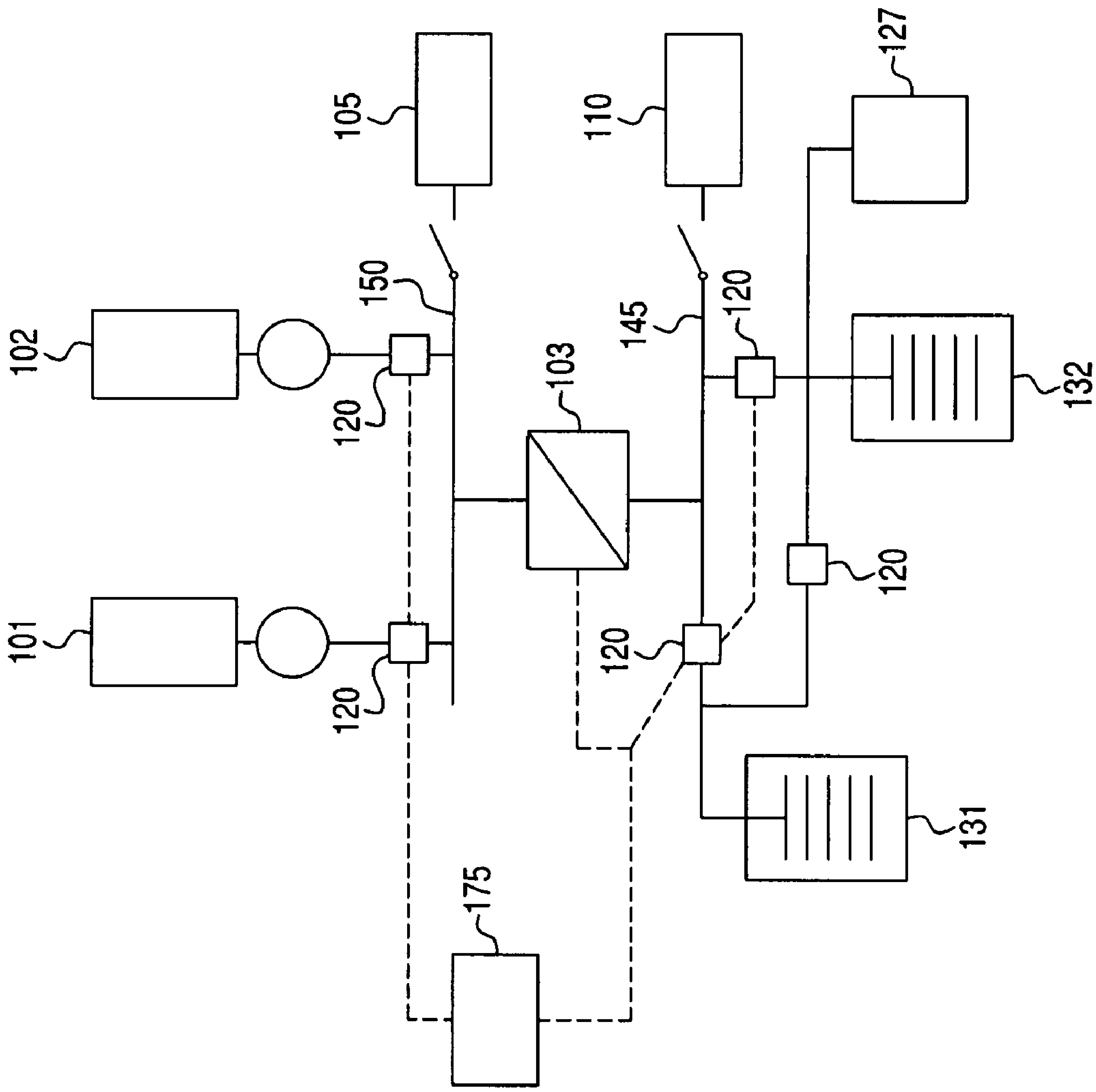


Fig. 15

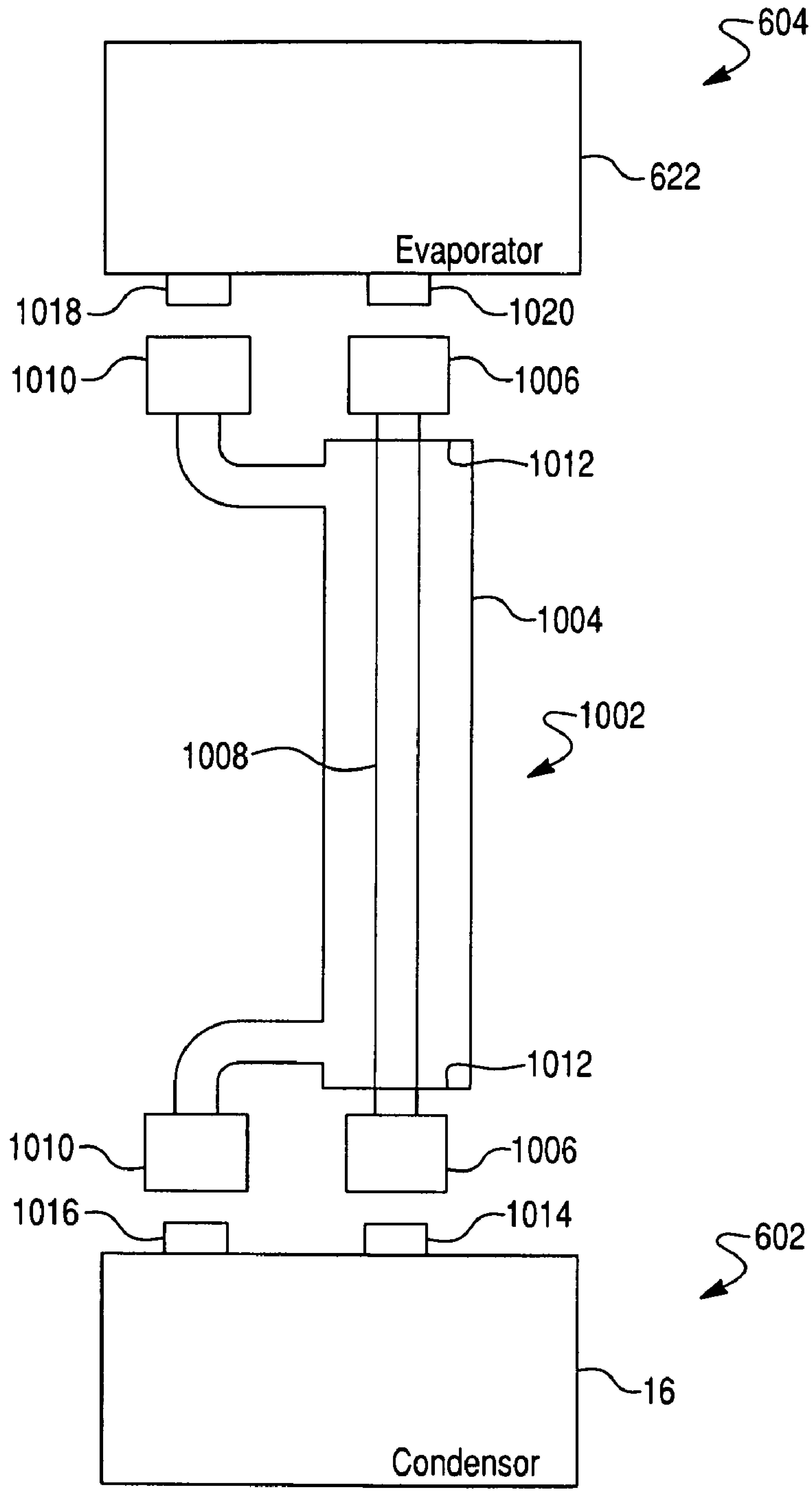

604
622
Evaporator
1018
1020
1010
1006
1012
1004
1002
1008
1012
1010
1006
1016
1014
602
16
Condensor

Fig. 16(a)

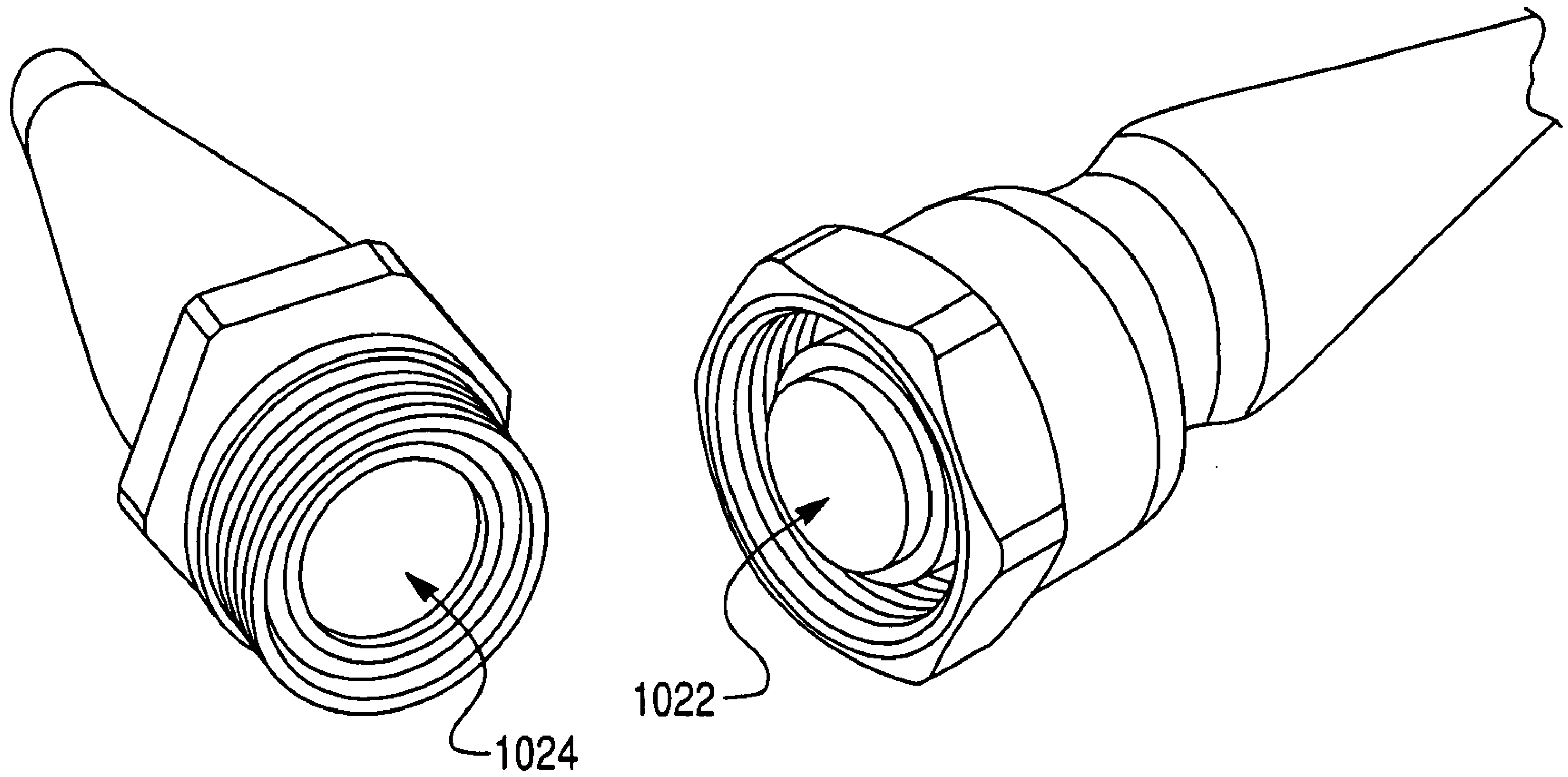
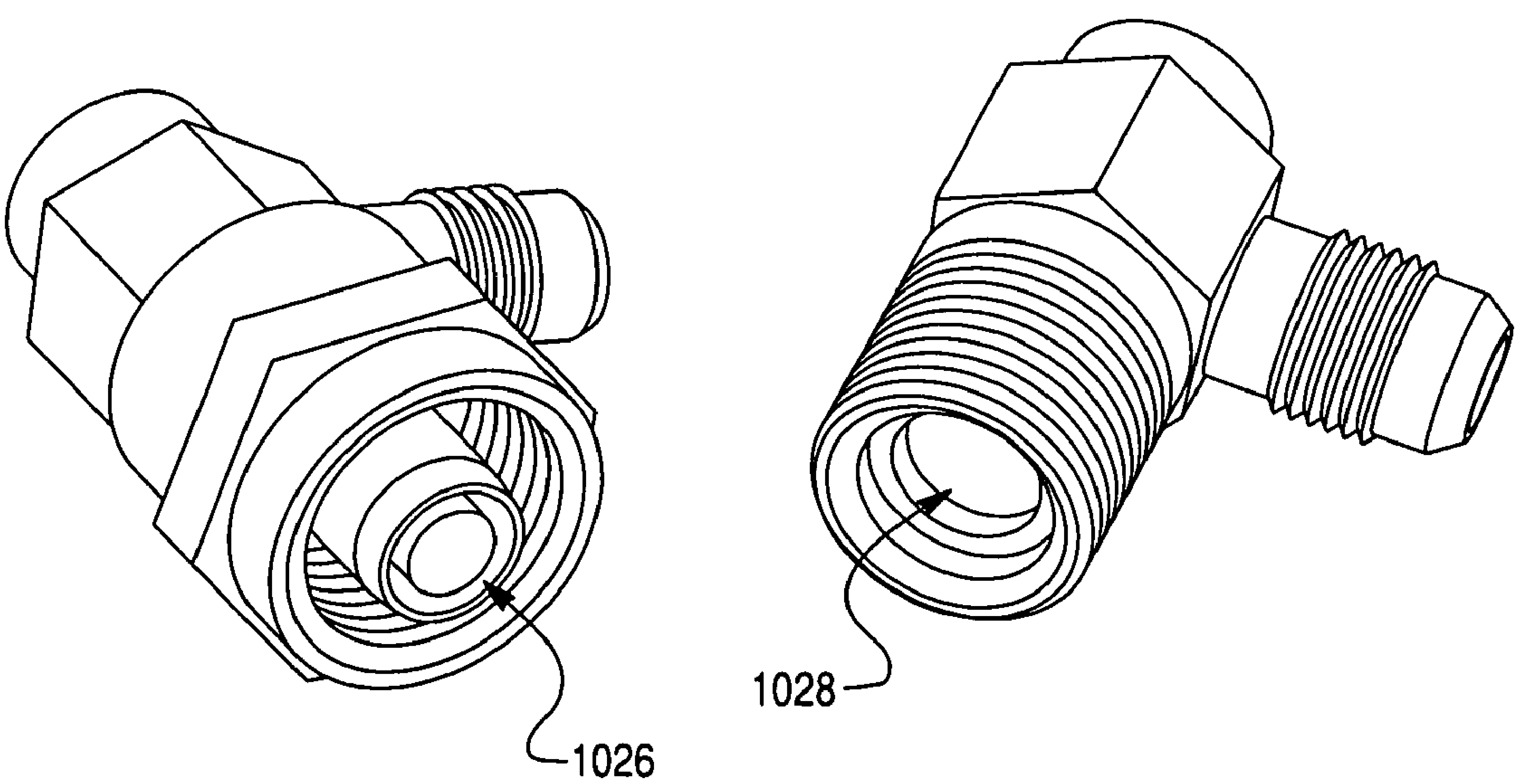


Fig. 16(b)



POWER GENERATION AND BATTERY MANAGEMENT SYSTEMS

This application is a continuation-in-part of U.S. patent application Ser. No. 11/560,160 filed on Nov. 15, 2006, which is incorporated by reference herein in its entirety.

BACKGROUND

The present invention relates to a battery management controller to be used with a power generation system in a vehicle.

One example of a power generation system that could benefit from the disclosed battery management controller is a truck HVAC system. However, the present invention is not limited to truck HVAC systems and the reference herein to such a system is for exemplary purposes only.

Truck drivers that move goods across the country may be required to pull over at various times along their journey so as to rest so that they do not become too fatigued. Common places for truck drivers to rest include rest stops, toll plazas, and the like. However, these locations usually do not have any accommodations for the drivers, and as a result they usually remain inside the cab of the truck inside a sleeping compartment. To provide the driver with maximum comfort, the sleeping compartment should be temperature controlled so that the environment in the truck is conducive for the driver to get the rest he or she needs.

Currently, trucks tend to use engine-belt driven compressors for the air conditioning system to circulate and pump refrigerant throughout the vehicle to cool the driving compartments. In addition, an engine-belt driven pump may circulate engine waste heat throughout the driving compartments when heating is required. Unfortunately, these systems have the drawback of not being able to operate when the engine is turned off. As a result, the driver has the choice of either keeping the engine running (which requires additional fuel) so as to run the temperature control system or turning the engine off and not using the air conditioning or heating systems (which may make the driver uncomfortable).

SUMMARY

According to one embodiment of the present invention, a power system to be installed in a vehicle may comprise a first battery having a first battery voltage; a second battery having a second battery voltage; an electrical power generator configured to charge the first battery; an electrical load powered by at least one of the first battery, the second battery or the electrical power generator; a converter; and a battery management controller. The converter is connected to both the first and second batteries and configured to operate in either a neutral mode or a first battery charging mode or a second battery charging mode. The converter is configured to create a voltage difference between the first and second batteries in the charging modes. The battery management controller is configured to monitor the first voltage of the first battery and the second voltage of the second battery and/or to monitor the current flow to and from the first and second batteries. The controller controls the operation of the converter to operate in either the neutral mode, the first battery charging mode or the second battery charging mode. In the second battery charging mode, the converter is configured to adjust the voltage difference between the first battery and the second battery to cause current to flow from the first battery to the second battery to thereby charge the second battery.

According to another embodiment of the present invention, a vehicle power system may comprise an electrical generator driven by an engine of a vehicle; a main battery connected to a secondary battery for supplying current to an electrical load; and a controller. The controller is coupled to the main battery and the secondary battery. The controller is configured to adjust the system so that the main battery is charged by the secondary battery when a state of charge of the main battery is below a predetermined threshold even when a state of charge of the secondary battery is less than the state of charge of the main battery.

According to another embodiment of the present invention, a vehicle may comprise: an interior area including a driver compartment and a sleeper compartment; an interior subsystem comprising a blower and an evaporator; an exterior subsystem; and a liquid phase cooler. The exterior subsystem may comprise a compressor and a condenser, wherein the exterior subsystem is mounted to a location outside the interior area. The interior subsystem may be mounted within the interior area and be operably connected with the exterior subsystem. The liquid phase cooler may comprise an outer tube with two first connectors and an inner tube with two second connectors, wherein the inner tube is placed within the outer tube.

According to another embodiment of the present invention, an air conditioning system for use in an over-the-road vehicle may comprise: a variable-speed compressor for providing refrigerant to a heat exchanger positioned to provide temperature control to an interior compartment of a vehicle; a brushless DC motor operably coupled to the variable-speed compressor; an evaporator; and an controller operably coupled to the motor. The controller may receive electric power from at least one source of electric power operable when an engine of the vehicle is not operating. The controller may modulate compressor speed of the compressor such that the evaporator is maintained at a predetermined evaporator temperature.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only, and are not restrictive of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, aspects and advantages of the present invention will become apparent from the following description, appended claims, and the accompanying exemplary embodiments shown in the drawings, which are briefly described below.

FIG. **1** is a schematic diagram of an HVAC system to be installed in a vehicle.

FIG. **2** is a schematic diagram of an HVAC system according to another exemplary embodiment.

FIG. **3** is a schematic diagram of an alternative configuration of the HVAC system of FIG. **2**.

FIG. **4** is a schematic diagram of an HVAC system according to another exemplary embodiment.

FIG. **5** is a schematic diagram of a power system according to an embodiment of the present invention.

FIG. **6**(*a*) is flow chart showing the operation of the power system during an accessory run mode.

FIG. **6**(*b*) is flow chart showing the operation of the power system during an engine start mode.

FIG. **6**(*c*) is a flow chart showing the operation of the power system during a recharging mode.

FIG. **7** shows a schematic diagram of a power system according to another embodiment of the present invention.

FIG. **8** shows a schematic diagram of a power system according to another embodiment of the present invention.

FIG. **9** shows a schematic diagram of a power system according to another embodiment of the present invention.

FIG. **10** shows a schematic diagram of a power system according to another embodiment of the present invention.

FIG. **11** is a schematic diagram of a HVAC component controller.

FIG. **12** is a flow chart showing the operation of the HVAC component controller.

FIG. **13** is a schematic diagram of an HVAC system to be installed in a vehicle.

FIG. **14** is a power generation system including a battery management controller.

FIG. **15** is a liquid phase cooler connecting the interior and exterior subsystems of FIG. **13**.

FIG. **16**(*a*) is a perspective frontal view of low-loss quick connectors for connecting the liquid phase cooler according to an embodiment of the present invention.

FIG. **16**(*b*) is a perspective frontal view of one-time quick connectors for connecting the liquid phase cooler according to an embodiment of the present invention.

DETAILED DESCRIPTION

Hereinafter, various embodiments of the present invention will be described in detail with reference to the drawings.

FIG. **1** is a schematic diagram of an HVAC system to be installed in a vehicle according to an embodiment of the present invention. The HVAC system **10** may comprise a motor **12**, a compressor **14**, circulation blowers **210** and **212**, an HVAC component controller **50**, and a power system **70**. The motor may be operatively coupled to the compressor **14**. The compressor **14** is a stepless continuously variable speed compressor, which is driven by the motor **12**. The compressor **14** circulates refrigerant through the condenser **16** to an optional refrigerant receiver and dryer **18**. From the refrigerant receiver and dryer **18**, the refrigerant then passes to either a first cooling path **21** that cools the driving compartment **23** or a second cooling path **25** that cools the sleeping compartment **27** of the vehicle. As to the first cooling path **21**, the refrigerant passes through a refrigerant metering device **20** and an evaporator **22**. The refrigerant metering device **20** may or may not be an expansion device, such as a thermostatic expansion valve, a pressure control expansion valve, a capillary tube, or the like, used in the conventional way. In one arrangement, the refrigerant metering device **20** is a metering device feeding refrigerant into the flooded evaporator **22** with no expansion taking place at or near the valve **20**, and thus merely meters in liquid refrigerant at a rate sufficient to maintain the correct liquid level in the evaporator. Air is blown over the evaporator **22** by the circulation blower **210**. After the air is cooled by the evaporator **22**, the air proceeds through an air duct **272** towards the driving compartment **23** of the vehicle.

A second cooling path **25** runs parallel to the first cooling path **21** in which the refrigerant is provided through a refrigerant metering device **24** and an evaporator **26**. Air is blown over the evaporator **26** by a circulation blower **212**. After the air is cooled by the evaporator **26**, the air proceeds through an air duct **276** towards the sleeping compartment **27** of the vehicle. The evaporator **26** of the second cooling path **25** may be smaller than the evaporator **22** of the first cooling path **21** because the sleeping compartment **27** is typically smaller than the driving compartment **23**.

The two coolant loops may be selectable through the use of valves **28** and **29**. The inclusion of such valves permits the driving compartment **23**, the sleeping compartment **27**, or both compartments to be air conditioned at a particular time. The valves **28** and **29** may be controlled through the HVAC component controller **50** (to be discussed below). Once the refrigerant passes through the evaporator **22** and/or **26**, the refrigerant then passes through an optional refrigerant accumulator **30** before being returned to the compressor **14** to restart the process.

The motor **12** may be any suitable motor. For example, the motor **12** may be a brushless DC motor that is commutated by a square or trapezoidal wave form. In another example, the motor **12** may be a synchronous permanent magnet motor that is commutated with a sine wave. When the motor is driven by a sine wave, additional benefits may be obtained, such as better drive efficiency, better cooling and quieter operation.

By using a variable speed compressor **14** driven by a brushless DC or a synchronous permanent magnet motor **12**, the vehicle's HVAC system may be operated when the engine is turned on or when the engine is turned off. The variable speed compressor **14** also may permit the HVAC system **10** to operate at a lower capacity during the engine off operation to conserve the amount of stored energy available for usage by the system **10**. The control for this operation is provided by a HVAC component controller **50** that monitors various system parameters while a battery management controller **60** monitors the availability and status of the power sources on the vehicle and provides power to the HVAC system. The power sources and battery management controller **60** are part of a power system **70**, as seen in FIG. **5**. As will be described in more detail later, the power system **70** seen in FIG. **5** may have as its power sources a first power source **40**, a second power source **42**, and/or the vehicle's main electrical power generation system **44**.

In a similar manner, the circulation blowers **210** and **212** may also have stepless continuously variable speeds such that the circulation blowers may operate at a lower capacity during the engine off operation to conserve the amount of stored energy available for usage by the HVAC system **10**. The control for this operation is also provided by the HVAC component controller **50**.

The battery management controller **60** is configured such that the vehicle's HVAC system **10** is capable of being powered by the vehicle's main electrical power generation system **44**, which is available while the vehicle's engine is operating. When the vehicle's engine is off, the HVAC system **10** may be powered with a first power source **40** and/or a second power source **42** depending on the power levels of the power sources (as will be described later). In one embodiment, the first power source **40** may be the vehicle's one or more starter batteries while the second power source **42** may be one or more auxiliary deep-cycle batteries.

In the HVAC system **10**, the motor driven compressor **14** may have the ability to modulate its output from full capacity to low capacity. This ability to modulate allows the use of a single HVAC system that may be used for both high output for the time periods that the engine is operating, and low output during the time periods when the engine is turned off so as to continue to cool or heat the driving and/or sleeping compartments. The coordination of this modulation is provided by the HVAC component controller **50**, which reduces the speed of the compressor when the engine is turned off. This modulation extends the duration of the heating and cooling operations because the charge of the available power sources is expended more slowly. That is, with a reduced speed of the compressor, the electric power demand is reduced as well.

Another aspect of FIG. **1** is a heating mode of operation in which there is an air heater in each air duct that leads to the vehicle compartments. For example, the air heater **270** is disposed in the air duct **272** which leads to the driving compartment **23**. The air heater **274** is disposed in the air duct **276** which leads to the sleeping compartment **27**. The air heaters **270** and **274** may be any heater known in the art, such as an electric resistance-type heater. The advantage of using an electric resistance-type heater is that such a heater allows the heating function to be completed without relying on the engine or additional fuel by merely relying on the circulation blowers and the heaters, which are powered by the first and/or second power sources or the vehicle electrical power generation system. In a preferred embodiment, instead of the air ducts **272** and **276**, the air heaters **270** and **274** may be placed within the same enclosures as the circulation blowers **210** and **212** but still in the path of the gas stream which enters the vehicle and/or sleeping compartments. If the air heaters are in the same enclosures as the circulation blowers, there may be a reduction in the complexity of the installation.

To operate in the heating mode, the HVAC component controller **50** does not operate the compressor **14** but merely operates the circulation blower **210** and the air heater **270** to provide the necessary heating to the driving compartment and/or the circulation blower **212** and the air heater **274** to provide the necessary heating to the sleeping compartment. This configuration provides additional power consumption savings and allows for a longer operating duration in the heating mode. In the cooling mode of operation, the air heaters **270** and **274** are simply not activated. If temperature control is desired, the HVAC component controller **50** may preferably provide pulse width modulation control (PWM) of power to the air heaters **270** and **274**. Alternatively, temperature control may be performed by a control door known in the art (not shown) placed in each duct (if provided) to control the flow of air (which may or may not be cooled by the evaporators **22** and/or **26**) passing over the air heaters **270** and/or **274** to regulate the temperature of the air flowing into their respective vehicle compartments.

The embodiment of FIG. **1** may include alternative configurations. For example, the first or second cooling path may be eliminated such that there is only one expansion device, one evaporator, one blower, and no accumulator **30**. With this configuration only one vehicle compartment may be temperature controlled. Alternatively, ducting may be used to channel the temperature controlled air into separate channels in which a first channel goes to the driving compartment and a second channel goes to the sleeping compartment. In this embodiment, a control door or the like may be used to channel the temperature controlled air to one compartment to the exclusion of the other.

FIG. **2** is a schematic diagram of another embodiment of the HVAC system **10** according to another embodiment of the present invention. The HVAC system **10** of this embodiment includes a primary coolant loop **170** that includes a first refrigerant and a secondary coolant loop **172** that includes a second refrigerant. The first refrigerant in the primary coolant loop **170** is driven by the compressor **14** which passes through the condenser **16**, the receiver and dryer **18**, the refrigerant metering device **20**, the first refrigerant-to-second refrigerant heat exchanger **174**, and back to the compressor **14**.

In contrast, the second refrigerant in the secondary coolant loop **172** is driven by a low pressure liquid pump **176**. The fluid passes through a second refrigerant-to-air heat exchanger **178**, a heater **180**, and the first refrigerant-to-second refrigerant heat exchanger **174**. The first refrigerant-to-second refrigerant heat exchanger **174** serves as the heat exchange medium between the primary coolant loop **170** and the secondary coolant loop **172**. The second refrigerant-to-air heat exchanger **178** cools the air supplied by the circulation blower **210**, which then flows to the vehicle compartment with or without ducting. To provide heating of the vehicle compartment, the HVAC component controller **50** need only operate the low pressure liquid pump **176** and the heater **180** in the secondary coolant loop **172** and the circulation blower **210**. That is, no power is delivered to the compressor **14**, and as a result the amount of power consumption is further reduced, which extends the time duration that heating may take place.

FIG. **3** shows an alternative configuration of FIG. **2** in which there are two second refrigerant-to-air heat exchangers **178** and **182** in the secondary coolant loop **172**. One second refrigerant-to-air heat exchanger **178** may be used to provide cooling/heating to the driving compartment **23** while the other heat exchanger **180** may be used to provide cooling/heating to the sleeping compartment **27** with or without ducting. The passage of the liquid through either or both of the heat exchangers **178** and **182** may be selected by the HVAC component controller **50**, which, in turn, controls the valve **184** that leads to the heat exchanger **180** and the valve **186** that leads to the heat exchanger **178**. Thus, the control of the valves **184** and **186** permits the driving compartment **23**, the sleeping compartment **25**, or both compartments to be air conditioned or heated at a particular time.

FIG. **4** shows another embodiment of the present invention in which the HVAC system uses a reverse cycle heating system. The reverse cycle heating system also allows the heating function to be completed without relying on the engine or additional fuel by merely relying on the compressor and the circulation blowers, which are powered by the first and/or second power sources or the vehicle electrical power generation system. As with the embodiment shown in FIG. **1**, the HVAC system **10** of FIG. **4** may comprise a motor **12**, a compressor **14**, circulation blowers **210** and **212**, an HVAC component controller **50**, and a power system **70**. The motor may be a brushless DC or a synchronous permanent magnet motor, which is operatively coupled to the compressor **14**. The compressor **14** is a continuously variable speed compressor, which is driven by the motor **12**. Connected to the compressor is a reversing valve **502**, which allows the compressor to pump refrigerant in a cooling direction indicated by single arrows **520** or a heating direction indicated by double arrows **522**.

As to the cooling direction, the compressor **14** circulates refrigerant through a heat exchanger **504** (which functions as a condenser in the cooling mode as the hot compressed gas from the compressor condenses to a liquid as heat is given off) to a first flow path **510** that thermally treats air going to the driving compartment **23** and/or a second flow path **512** that thermally treats air going to the sleeping compartment **27** of the vehicle. As to the first flow path **510**, the refrigerant passes through a refrigerant metering device **20** and a heat exchanger **506** (which functions as an evaporator in the cooling mode as the liquid refrigerant boils and forms a gas as heat is absorbed by the refrigerant liquid). Air is blown over the heat exchanger **506** by the circulation blower **210**. After the air is cooled by the heat exchanger **506**, the air proceeds towards the driving compartment **23** of the vehicle.

A second flow path **512** runs parallel to the first flow path **510** in which the refrigerant is provided through a refrigerant metering device **24** and a heat exchanger **508** (which functions as an evaporator during the cooling mode as the liquid refrigerant boils and forms a gas as heat is absorbed by the refrigerant liquid). Air is blown over the heat exchanger **508** by a circulation blower **212**. After the air is cooled by the heat exchanger **508**, the air proceeds towards the sleeping compartment **27** of the vehicle. The heat exchanger **508** of the second flow path **512** may be smaller than the heat exchanger **506** of the first flow path **510** because the sleeping compartment **27** is typically smaller than the driving compartment **23**.

The two coolant loops may be selectable through the use of valves **28**, **29**, **514**, and **516**. The inclusion of such valves permits the driving compartment **23**, the sleeping compartment **25**, or both compartments to be air conditioned at a particular time. The valves **28** and **514** are opened and the valves **29** and **516** are closed when only the driving compartment is being temperature controlled. By a similar token the valves **29** and **516** are opened and the valves **28** and **514** are closed when only the sleeping compartment is being temperature controlled. The valves **28**, **29**, **514**, and **516** may be controlled through the HVAC component controller **50**. Once the refrigerant passes through the heat exchanger **506** and/or **508**, the refrigerant then returns to the reversing valve **502** and the compressor **14** to restart the process.

As to the heating direction, the reversing valve **502** is switched such that the refrigerant pumped by the compressor flows in the reverse direction as indicated by double arrows **522**. Thus, the compressor causes the refrigerant to flow through the first flow path **510** and/or the second flow path **512** depending if the valves **28** and **514** and the valves **29** and **516** are opened or closed. If the valves **28** and **514** are opened, the refrigerant flows through the heat exchanger **506** (which functions as a condenser in the heating mode as the hot gas is condensed to a liquid as it gives up heat). Air is blown over the heat exchanger **506** by the circulation blower **210**. After the air is heated by the heat exchanger **506**, the air proceeds towards the driving compartment **23** of the vehicle. Meanwhile, the refrigerant continues from the heat exchanger **506** through the refrigerant metering device **20** to the heat exchanger **504** (which functions as an evaporator in the heating mode). After flowing through the heat exchanger **504**, the refrigerant returns to the reversing valve **502** and the compressor **14**.

If the valves **29** and **516** are opened, the refrigerant flows through the heat exchanger **508** (which functions as a condenser in the heating mode). Air is blown over the heat exchanger **508** by a circulation blower **212**. After the air is heated by the heat exchanger **508**, the air proceeds towards the sleeping compartment **27** of the vehicle. Meanwhile, the refrigerant continues from the heat exchanger **506** through the refrigerant metering device **24** to the heat exchanger **504** (which functions as an evaporator in the heating mode). After flowing through the heat exchanger **504**, the refrigerant returns to the reversing valve **502** and the compressor **14** to restart the process.

Similar to the embodiment shown in FIG. **1**, the embodiment of FIG. **4** may include a variable speed compressor **14** driven by a brushless DC or a synchronous permanent magnet motor **12**; the control for the heating and cooling operations being provided by the HVAC component controller **50**. The available power sources may come from the power system **70**, which may include a first power source **40**, a second power source **42**, and/or the vehicle's main electrical power generation system **44** as seen in FIG. **5**. The circulation blowers **210** and **212** may also have continuously variable speed which may be controlled by the HVAC component controller **50**; and the battery management controller **60** of the power system **70** may monitor and control the available power sources when the engine is turned off.

Also as with the embodiment of FIG. **1**, FIG. **4** may include alternative configurations. For example, the first or the second cooling path may be eliminated such that there is only one refrigerant metering device, one heat exchanger in which air passes over, and one blower. With this configuration only one vehicle compartment may be temperature controlled. Alternatively, ducting may be used in which the duct channeling the temperature controlled air may be spit into multiple channels such that a first channel goes to the driving compartment and a second channel goes to the sleeping compartment. In this embodiment, a control door or the like may be used to channel the temperature controlled air to one compartment to the exclusion of the other.

The power requirements and operation of the HVAC system **10** are handled by the battery management controller **60** of the power system **70** and the HVAC component controller **50**, respectively. The two controllers **50** and **60** may be software control loops with associated hardware or circuitry, and they may be physically housed in separate devices or the same device.

The power system **70** with the battery management controller **60** will now be discussed with reference to FIG. **5**. The power system **70** may comprise a first power source or battery **40**, a second power source or battery **42**, an electrical power generator **76** in an electrical generation system **44**, an electrical load **78**; a first regulator or converter **72**, a second regulator **73**, a third regulator **74**, a user interface **51**, and a battery management controller **60**. The first regulator or converter **72**, the second regulator **73**, the third regulator **74**, and the battery management controller **60** may constitute a power management module. The power management module may also include the user interface **51**, temperature and voltage sensors **63**, sensors for monitoring current flow to and from the first and second power sources, and/or the HVAC component controller **50**. The components of the power management module may be or may not be contained within a single housing.

In one exemplary embodiment, a truck may have seven batteries in which four batteries are connected in parallel to provide a high capacity first battery bank as the first power source **40** and the three remaining batteries are connected in parallel to provide a second, somewhat smaller battery bank as the second power source **42**. For the following discussion, the first power source **40** will be called the first battery (which may be a single battery or a plurality of batteries in a battery bank) and the second power source **42** will be called the second battery (which may be a single battery or a plurality of batteries in a battery bank). The first battery **40** can have a first battery voltage and the second battery **42** may have a second battery voltage that is different from the first battery voltage.

The first battery **40** and/or the second battery **42** may be connected to the first regulator **72**, the second regulator **73**, and temperature and voltage sensors **63**. Also, one of the first and second batteries is also connected to the vehicle starting system to provide power to start the engine of the vehicle, for example, by being connected to the engine starter **64**. In the embodiment of FIG. **5**, the first battery **40** may be, for example, one or more starter batteries which are used to start up the vehicle upon ignition. Accordingly, the first battery **40** may be connected to the engine starter **64**. According to one embodiment of the present invention, the first battery may be a lower quality battery than the second battery such that it may not be desirable to discharge the first battery to more than 20-30%. Alternatively or additionally, the first battery may be a secondary or auxiliary battery while the second battery may be the main battery of the vehicle. The second (main) battery can be connected to the first (secondary battery) for supplying current to the electrical load **78**.

The temperature and voltage sensors **63** may monitor the voltage and temperatures of the first and second batteries **40** and **42**. Additionally or alternatively, sensors for monitoring the current flow to and from the first and second batteries may be used. These sensors may be used to monitor the state of charge of the batteries so as to prevent the batteries from being overly discharged.

The engine starter **64** is connected to one of the batteries so as to provide enough power to start the engine of the vehicle. The engine starter **64** may be electrically directly connected to the first battery, directly connected to the second battery, and/or directly connected to one of the first and second batteries while the other of the first and second batteries is connected to the engine starter through the second regulator or converter **73**. In FIG. **5**, the engine starter **64**, for example, is directly connected to the first battery **40** and is indirectly connected to the second battery **42** via the first battery **40** and the second regulator **73**.

The electrical power generation system **44** comprises an electrical power generator **76** configured to charge the first battery **40**, the second battery **42**, and/or run the electrical load **78**. Although the embodiment of FIG. **5** shows that the electrical power generator **76** is not directly connected to the load **78**, it is contemplated that the generator **76** may be directly connected to the load **78**. In one embodiment, the electrical power generator **76** is an alternator, such as a truck alternator, configured to be driven by the engine of the vehicle. The alternator may be configured such that, when the engine is on and running idle, the HVAC system should be able to run at maximum speed and load while the alternator provides maximum charging capacity for the batteries at the same time. For example, the alternator may be rated for 250 A, 24 V or 500 A, 12 V. In such an embodiment, the battery management controller **60** is configured to control the excitation of the alternator to control the alternator output voltage.

The first regulator **72** may be a current regulator, which is connected to the electrical power generator **76** and to at least one of the first and second batteries **40** and **42**. The battery management controller **60** controls the current regulator **72** so as to regulate the amount of current flowing from the generator **76** to the at least one of the first and second batteries **40** and **42**. According to the embodiment of FIG. **5**, the first regulator **72** is connected to both the first and second batteries **40** and **42**, and thus may be controlled by the battery management controller **60** to regulate the amount of current flowing from the generator **76** to both the first and second batteries. In other words, the first regulator **72** may charge up the first battery **40**, charge up the second battery **42**, and/or run the components of the HVAC system **10** based on commands from the battery management controller **60**. The first regulator **72** may be a DC-to-DC converter, such as a buck DC regulator or a buck/boost DC regulator and selector.

The second regulator **73** may connect the first and second batteries **40** and **42** together to control the current flow between the first and second batteries. The regulator **73** may be a DC-to-DC converter, such as a buck/boost DC regulator and selector. The second regulator **73** may be a converter that is controlled by the battery management controller **60** to operate in a neutral mode, a first battery charging mode, or a second battery charging mode. In the first and second battery charging modes, the second regulator or converter **73** is configured to create a voltage difference between the first and second batteries. For example, in the first battery charging mode, the second regulator **73** is configured to adjust a voltage difference between the first and second batteries so as to cause current to flow from the second battery to the first battery to thereby charge the first battery, regardless of the respective charges of the two batteries. That is, current can flow from the second battery to the first battery even if the first battery may have a charge that is greater than, equal to, or less than the charge of the second battery. Thus, the battery management controller **60** coupled to the first and second batteries (for example, secondary and main batteries, respectively) is configured to adjust the system so that the first (secondary) battery is charged by the second (main) battery when a state of charge of the first (secondary) battery is below a predetermined threshold even when a state of charge of the second (main) battery is less than the state of charge of the first (secondary) battery.

In the second battery charging mode, the second regulator **73** is configured to adjust the voltage difference between the first battery and the second battery so as to cause current to flow from the first battery to the second battery to thereby charge the second battery, regardless of the respective charges of the two batteries. That is, current can flow from the first battery to the second battery even if the second battery may have a charge that is greater than, equal to, or less than the charge of the first battery. Thus, the battery management controller **60** coupled to the first and second batteries (for example, secondary and main batteries, respectively) is configured to adjust the system so that the second (main) battery is charged by the first (secondary) battery when a state of charge of the second (main) battery is below a predetermined threshold even when a state of charge of the first (secondary) battery is less than the state of charge of the second (main) battery.

In the neutral mode, the second regulator **73** is configured so that no current flows between the first and second batteries. For example, the battery management controller **60** may be configured to operate the second regulator **73** in the neutral mode so as to break the connection between the first and second batteries to prevent current from flowing between the two. Alternatively, the battery management controller **60** may be configured to operate the second regulator **73** in the neutral mode so as to adjust the voltage difference between the first and second batteries to prevent current from flowing between the first and second batteries.

The third regulator **74** may be a boost DC regulator connected to at least one of the first and second batteries **40** and **42** and to the load **78** (for example, one or more components of the HVAC system **10**). The boost converter raises the voltage being supplied to the load by the at least one of the first and second batteries **40** and **42**. In the embodiment of FIG. **5**, the boost converter **74** is connected between the second battery **42** and the load **78**. Thus, the boost converter of FIG. **5** raises the voltage being supplied to the load by the second battery **42**.

The electrical load **78** may be powered by at least one of the first battery **40**, the second battery **42**, and/or the electrical generator **76**. The load **78** may be components of the HVAC system **10** for either heating or cooling the compartment of the vehicle and/or other electrical power accessories, such as microwave ovens, televisions, stereos, refrigerators, etc.

The battery management controller **60** provides the following functions: (1) to monitor the first voltage of the first battery **40** and the second voltage of the second battery **42** and/or to monitor current flow to and from the first and second batteries **40** and **42**; (2) to control the operation of the second regulator or converter **73** to operate in either the neutral mode, the first battery charging mode or the second battery charging mode; (3) to control the first or current regulator **72** and the second regulator or converter to adjust the relative charging rates of the first and second batteries; (4) to control the third regulator or boost converter **74** to adjust the power being supplied to the load **78** from the at least one of the first and second batteries **40** and **42**; (5) to control the power system **70** to conduct an equalization charge of one of the first (secondary) battery and the second (main) battery using the other of the first and second batteries; (6) to control the electrical generator to raise an output voltage to an increased value greater than a normal output voltage in order to conduct an equalization charge on one of the first (secondary) battery and the second (main) battery; and/or (7) to control the first or current regulator **72** so as to increase the amount of current flowing from the generator to the one of the first (secondary) battery and the second (main) battery.

The battery management controller **60** may also fulfill a variety of other different purposes including: (1) maximizing the electrical power available for use by the HVAC system; (2) ensuring that sufficient electrical reserve power is available to start the engine; (3) tracking historical use (charge and discharge) of all connected batteries; (4) determining the current state of charge of all connected batteries; (5) determining the current end-of life status of all connected batteries irrespective of their respective charge level; (6) ensuring that the charge and discharge cycles of all connected batteries are consistent with the user's preferred compromise between battery longevity and available stored energy; and (7) preventing the overloading of the battery charging system.

The battery management controller **60** may comprise a control logic circuit **66** and a memory **67**. The battery management controller **60** carries out its function by being connected to the voltage and temperature sensors **63**, the first regulator **72**, the second regulator **73**, the third regulator **74**, the electrical power generation system **44**, a user interface **51** (which may comprise a display **310** and one or more input devices **312**), and the HVAC component controller **50**.

The memory **67** of the battery management controller may be any suitable storage medium, such as a ROM, a RAM, an EEPROM, etc. The memory **67** is used to store a plurality of data to be utilized by the battery management controller **60** when controlling the components of the power system **70**. For example, the memory **67** may be used to log historical data obtained during previous charge and discharge cycles, such as voltage and temperature levels, and use the historical data to modify the permitted depth of discharge to ensure the completeness of future charge cycles. For example, to ensure that the batteries are fully recharged between cycles to prevent premature sulfation and destruction of the batteries, the battery management controller may monitor and store the time and power levels of the batteries during the discharge and recharge cycles. This historical data may verify that, in a typical discharge and re-charge cycle, sufficient time and power is available to fully recharge the batteries. If there is not sufficient time and power to fully recharge, the control logic circuit **66** may respond by raising the minimum battery cut-off voltages thereby reducing the total amount of power which may be drawn from the batteries. In other words, the battery management controller **60** may be configured to be self-learning which allows the controller to maximize the battery replacement life by monitoring the first and/or second power sources such that they are not excessively discharged (i.e., drained) and such that they are not discharged to a level that does not allow the power source to be fully recharged during the typical engine run time. For example, consider that a power source might be a battery in which the battery may be safely discharged to a level X. Thus, the level X may be the predetermined amount value during the determination of whether the power source should be connected to the HVAC system. However, if the run cycle of the engine was too short to allow the battery to fully recharge during the engine run after the battery had been partially discharged, the battery would still be prematurely destroyed because failure to fully recharge a battery is just as harmful as discharging it too deeply (or draining the charge too much). To prevent the premature destruction of a battery due to it not being fully recharged, the battery management controller **60** may monitor the battery charge in the power source to determine if the battery was fully recharged. If the battery was not, then the controller **50** may be configured to "learn" during the next operation where the power source is connected and the engine is turned off such that the battery should be less deeply discharged, i.e., the battery should be discharged to a level Y, which is greater than the level X. Then, the level Y may be the predetermined amount value during the determination of whether the power source should be connected to the HVAC system. In more simplified terms, if a battery (such as the first battery **40** or the second battery **42**) can only be recharged at a certain charge rate and if a user has a tendency to run the engine of the vehicle for an amount of time shorter than is necessary to fully charge the battery when it is discharged to a certain level, this information is used by the battery management controller **60** to modify the allowed amount that the battery can be discharged. Thus, with the modified level of allowed discharge, the battery will be more likely to be fully charged after the engine has been run for that user's typical amount of time.

The memory **67** can also store data that is useful in determining the current state of charge of the batteries. For example, in a more conventional HVAC system, the measurement of the battery voltage under load is used to determine the state of charge. While this method is low in cost and easy to implement, it is also highly inaccurate. The voltage may be used to accurately determine the state of charge but only when such measurements are taken in conjunction with temperature and only after the battery has been "at rest" (i.e., unloaded) for a period or time (typically over one hour). However, the battery management controller **60** of FIG. **5** may use multiple sources of historical data (stored in the memory **67**) and real-time data to more accurately determine the current amount of stored energy available for use. Additionally, the battery management controller **60** allows highly accurate "resting voltage" measurements of the state of charge to be made of the power reserve and to be stored even when portions of the battery power supply are still in use.

The control circuitry **66** of the battery management controller **60** may comprise the necessary hardware, software, or other mechanisms necessary to carry out the functions to which it was designed.

The user interface **51** may include a display **310** and input devices **312**. The display **310** of the user interface **51** may provide a user, such as a vehicle occupant, information related to the status of the HVAC system **10** and/or the power system **70**. The display may include one or more of an alphanumerical display, a graph, or the like. For example, the display may include the vehicle's interior ambient temperature, the exterior ambient temperature, the circulation blower speeds, the usage of the power source or sources supplied to the HVAC system **10**, and warning messages, etc. In one example, if the first power source and the second power source are batteries, the display may show the current approximate battery charges for each power source to the vehicle occupant.

One or more input devices **312** may also be a part of the user interface. The input devices may be one or more of a keyboard, a control panel, or the like, so that the vehicle occupant may input user preferences for the operation of the HVAC system **10** and the power system **70**. For example, the user preferences may include the operating mode of the HVAC system such as off, heating, and cooling modes of operation. Also, the input device **312** of the user interface may allow a user, such as a vehicle occupant, to select the operating mode of the second regulator or converter **73**, for example, the neutral mode, the first battery charging mode, or the second battery charging mode.

Below is a discussion of the processes that occur during the accessory run mode when the batteries are discharging when in the engine is turned off, the engine start-up mode, and recharge mode when the batteries are being recharged when the engine is turned on.

The process that the power system including the battery management controller undergoes during an accessory run (discharging) mode is provided in FIG. **6**(*a*). The discharging of the first and/or second batteries occurs when the engine is turned off and an accessory or a plurality of accessories is turned on as shown in step **402**. Although the foregoing discussion talks of only one accessory being powered, it is understood the same discussion applies to when a plurality of accessories are being powered. According to one example the accessory may be the HVAC system **10** for heating or cooling the compartment of the vehicle. The battery management controller **60** ("BMC") determines a minimum acceptable state of charge for both batteries based on preset base limits, historical charge/discharge levels, priority battery conditions, user inputs, and temperature as shown in step **404**. In step **406**, the battery management controller **60** through its control circuit **66** determines the state of charge and condition of the first and second batteries by using the current voltage and temperature of the batteries from data received by the voltage and temperature sensors **63** and optionally the historical data stored in the memory **67** of the controller **60**. The battery management controller then determines if the first battery has sufficient charge and if the second battery has sufficient charge.

If neither battery has sufficient charge, the process proceeds to step **408** in which the user is notified that there is insufficient battery charge to run the accessory. The accessory is turned off, and the process ends at step **409**.

If only the first battery has sufficient charge, the process proceeds to step **410** in which the battery management controller **60** selects the first battery **40** as a power source and the accessory is operated at step **412**. The current from the first battery **40** runs through the second battery **42** as it travels from the first battery **40** through the third regulator **74** to the load **78**. As the accessory is running, the state of charge for the first battery is monitored by the controller **60** at step **414**, and if the state of charge of the first battery falls below a predetermined level, the first battery is deselected at step **416**.

At step **418**, the second battery is monitored to determine if it has sufficient state of charge to run the accessory. Although the second battery did not have sufficient charge in step **406**, the charge of the second battery may have replenished after sitting around for a while. In the event that the second battery replenishes sufficiently to be used as a power source for the accessory, the second battery can be used to power the accessory.

At step **420**, there is a comparison between the projected accessory run time (based on state of charge of the second battery and/or user input) and the historical run time. For example, the power draw (current) from the HVAC system **10** is monitored and the rate of decline in the battery is noted. The power draw and rate of decline is compared to historical data to determine the approximate state of sulfation of the battery plates and from this comparison, the approximate condition of the battery is deduced. Under a given load, the voltage of batteries in poor condition will decline faster than batteries in good condition. Consequently, it may be predicted that batteries in poor condition will have less total stored energy even though the actual voltage at any given time may be the same. In one example, data may be collected related to the maximum battery discharge and/or the average battery discharge during an operation cycle of the batteries. This data may be compiled over time such that a history of the maximum and/or average battery discharge is stored in the memory **67** in the battery management controller **60**.

As another example, user preferences which are inputted using the user interface **51** are also factors that influence the extent to which the batteries **40** and **42** will be allowed to be discharged. One example is the battery replacement life. Battery replacement life is related to the depth of the discharge of the power source as well as the rate of discharge, i.e., a function of the minimum battery voltage adjusted by the load. For example, a lightly loaded battery which is consistently discharged to 11.8 V may only last through 100 charge/recharge cycles while a heavily loaded battery that was consistently discharged to 11.8 V might last 200 charge/recharge cycles. If a user preference is set for a long battery life, the batteries will be less deeply discharged and will last longer. However, because less stored energy will be available for use, more batteries will need to be carried to supply a given amount of cooling or heating than would be the case if a shorter battery life (and more deeply discharged batteries) were selected.

Based on the comparison of the projected accessory run time and the historical run time, the battery management controller **60** will send a signal to the HVAC component controller **50** so as to adjust the running of these components so as to enable the operation of these components for the full desired amount of time, as shown in step **422**. As the voltage of the second battery is being discharged, in step **424**, the battery management controller will continue to monitor the state of charge of the second battery, and send signals to the HVAC component controller so as to adjust the running of the accessories based on the current state of charge.

With continued operation of the HVAC system **10**, the voltage of the first battery **40** continues to decline. The battery management controller logic circuit re-analyzes the battery **40** by comparing real time data on the power draw, the temperature and the rate of voltage decline with the stored historical data and the user input preferences to determine the amount of stored energy available.

A determination is made of the minimum system disconnect voltage, i.e., the battery cut-out voltage. From this determination, a calculation is made of the estimated time to battery depletion for the first battery and this estimated time information is communicated to the HVAC component controller **50**. Because the estimated time information is based on both static data (such as historical and user input) and real-time data (such as current voltage levels and temperatures), a change in the performance, the system load or the ambient conditions during the operation of the HVAC system **10** may change the estimated time information which may increase or decrease the calculation of the available system run time. As long as there is sufficient voltage, the battery management controller will continue to have the second battery power the accessory and monitor the second battery's voltage level (and/or the current flow to and from the battery). However, the power may eventually be depleted from the second battery **42** to the point where the voltage falls to the level calculated by the control logic circuit to be the minimum allowed, i.e., the battery cut-out voltage, and disconnect the second battery **40**. Once the state of charge of the second battery falls below the minimum allowed level, the process proceeds to steps **408** and **409** in which the user is notified via the user interface of the insufficient battery charged to run the accessory and the accessory is turned off.

Referring back to step **406**, if only the second battery is determined to have sufficient charge to run the accessory, the process proceeds to step **426** in which the accessory starts running while only using the second battery as the power source. As the accessory is running, the state of charge for the second battery is monitored by the controller **60** at step **414**. Step **416** does not really take place because the first battery was never selected as the power source for the accessory so there is no need to deselect it. Thus, from step **414**, the process may then proceed to step **418**. At step **418**, the second battery is monitored to determine if it has sufficient state of charge to run the accessory.

At step **420**, there is a comparison between the projected accessory run time (based on the state of charge of the second battery and/or user input) and the historical run time, as previously described. Based on the comparison of the projected accessory run time and the historical run time, the battery management controller **60** will send a signal to the HVAC component controller **50** so as to adjust the running of these components so as to enable the operation of these components for the full desired amount of time, as shown in step **422**. In step **424**, the battery management controller will continue to monitor the state of charge of the second battery, and send signals to the HVAC component controller to adjust the running of the accessories based on the current state of charge. Once the state of charge of the second battery falls below a predetermined level, the process proceeds to steps **408** and **409** in which the user is notified via the user interface of the insufficient battery charged to run the accessory and the accessory is turned off.

Referring back to step **406**, if both the first and second batteries are determined to have sufficient charge to run the accessory, the process proceeds to step **428** in which the accessory started running while both batteries are used as the power source. As the accessory is running, the state of charge for each battery is monitored by the controller **60** at step **414**. As the accessory is running, the state of charge for the first battery is monitored by the controller **60** at step **414**, and if the state of charge of the first battery falls below a predetermined level, the first battery is deselected at step **416**. At step **418**, the second battery is monitored to determine if it has sufficient state of charge to run the accessory.

At step **420**, there is a comparison between the projected accessory run time (based on state of charge of the second battery and/or user input) and the historical run time, as previously described. Based on the comparison of the projected accessory run time and the historical run time, the battery management controller **60** will send a signal to the HVAC component controller **50** so as to adjust the running of these components so as to enable the operation of these components for the full desired amount of time, as shown in step **422**. In step **424**, the battery management controller will continue to monitor the state of charge of the second battery, and send signals to the HVAC component controller to adjust the running of the accessories based on the current state of charge. Once the state of charge of the second battery falls below a predetermined level, the process proceeds to steps **408** and **409** in which the user is notified via the user interface of the insufficient battery charged to run the accessory and the accessory is turned off.

The process that the power system including the battery management controller undergoes during an engine start mode is provided in FIG. **6**(*b*). Initially, the engine is turned off as shown in step **450**. An operator tries to start the engine at step **452**. At the start up of the engine, a heavy electrical load is applied to the first battery **40** causing the voltage of the first battery **40** to drop. The amount of drop depends on the condition, the state of charge, and the temperature of the first battery **40** as well as the engine itself. Thus, there is a chance that under certain adverse conditions, the voltage drop will be so severe as to prevent the engine from starting unless additional electrical power is made available. Alternatively or additionally, the discharge of the first battery may be at such a level that there is insufficient voltage for the engine starter. For example, the first battery may be already 80% discharged or even dead before applying the heavy electrical load. If the voltage or state of charge of the first battery is insufficient to start the engine, the battery management controller provides a "start assist" function in which the second battery is used to charge the first battery up to a level sufficient to start the engine.

At step **454**, the battery management controller **60** monitors the voltage or state of charge of the first battery **40** (or the current flow to and from the battery) to determine if it falls below a preset limit, for example, a voltage level that would prevent the first battery **40** from starting the engine. If the voltage of the first battery **40** does not fall below the preset limit, no further action is needed to be taken by the battery management controller **60** in regard to starting the engine, as indicated in step **456**, because there is sufficient voltage or charge in the battery to start the engine. Thus, the engine is started. If the voltage of the first battery **40** falls below the preset limit, but the engine starts anyway, as indicated in step **458**, no further action needs to be taken by the battery management controller **60** in regard to starting the engine, as indicated in step **456**. However, the battery management controller may command that the first battery be recharged, as will be discussed later.

If the voltage of the first battery **40** falls below the preset limit, and the engine fails to start, as indicated in step **460**, the process proceeds to step **462** wherein the battery management controller **60** notifies the user that the charging of the first battery is in process. The user may be notified through the display **51** and/or through any other suitable audio, visual, or tactile indicator. At step **464**, the battery management controller **60** then controls the second regulator or converter **73** to boost the voltage from the second battery **42** and use it to charge the first battery **40** (the first battery charging mode). This boosting is accomplished by the battery management controller adjusting a voltage difference between the connecting first and second batteries to cause current to flow from the second battery to the first battery to thereby charge the first battery. In a simplified example, each battery is connected to a DC-to-DC converter of the buck/boost type as a load/source. The determination of whether the first battery is a load (receiving current) or a source (sending current) depends upon the duty cycle of the switching transistor associated with it. Likewise, the determination of whether the second battery is a load (receiving current) or a source (sending current) depends upon the duty cycle of the switching transistor associated with it. The duty cycles of these switching transistor is determined and controlled by the battery management controller **60**.

At step **468**, the state of charge of the first battery **40** is monitored and determined by the battery management controller **60**. If the first battery **40** has sufficient charge, the process proceeds to step **470** wherein the user is notified by the display **51** and/or any other suitable audio, visual, or tactile indicator to retry starting the engine. From step **470**, the process proceeds back to step **452**. If the first battery **40** does not have sufficient charge, the recharging of the first battery **40** with the voltage of the second battery **42** continues but the battery management controller **60** also monitors the voltage of the second battery **42** (or the current flow to and from the battery). If the second battery **42** has sufficient charge, the recharging continues as indicated in step **472** and the state of charge of the first battery **40** is monitored and determined by the battery management controller **60** as indicated in step **468**.

If at any point, during the recharging, the battery management controller **60** determines that the second battery does not have sufficient charge to continue the recharging, the process proceeds to step **470** wherein the user is notified by the display **51** and/or any other suitable audio, visual, or tactile indicator to retry to start the engine. From step **470**, the process proceeds back to step **452**. Optionally, after a predetermined number of iterations, if the first battery does not gain sufficient charge to start the engine and the second battery does not have sufficient charge to recharge the first battery, the user can be notified by the display **51** and/or any other suitable audio, visual, or tactile indicator to cease attempting to start the engine.

To provide a more concrete example of the start assist function, if both the first and second batteries, for example, are each discharged 80% and neither battery alone is suitable to start the engine. The battery management system issues commands such that the last 20% charge left in the second battery **42** is channeled through the second regulator **73** into the first battery so as to charge up the first battery **40**. Even though the charge of the first battery **40** will become greater than the charge of the second battery during the process of charging up the first battery, the charging up process will still continue until the first battery is charged up to a level so that the first battery can be used to start the engine. For example, the first battery **40** will continue to be charged if the first battery is charged to 25% while the second battery is depleted down to 15%. If the engine can start with a battery charged to 30%, the charging process will continue to this point, even though the second battery may be depleted down to 10%. In this example, the second battery is used only to charge the first battery. This charging process may be more advantageous than merely directly coupling the first and second batteries to each other and then directly connecting the coupled batteries to the starter. For instance, in an example where the first battery is depleted and the second battery is fully charged, if both batteries are connected to each other, the second battery may be uncontrollably drained by the first battery instead of being used to start the engine.

The process that the power system including the battery management controller undergoes during a recharging mode is provided in FIG. **6**(*c*). Upon the start up of the engine, a charge power source, such as an electrical power generator **76** or alternator, is activated, as indicated in step **900**. The battery management controller **60** determines, in step **902**, the state of charge of the first and second batteries, and then proceeds to step **904**.

At step **904**, there is a determination of whether there has been any user input provided from the user interface **51**. For example, the user interface may be configured to allow a vehicle occupant to select the operating mode of the second regulator or converter. For example, if the user selected the first battery to be charged first, the process proceeds to step **905** in which the battery management controller controls the first regulator **72** to regulate the amount of current flowing from the generator so that it charges the first battery before the second battery. Similarly, if the user selected the second battery to be charged first, the process proceeds to step **905** in which the battery management controller controls the first regulator **72** to regulate the amount of current flowing from the generator so that it charges the second battery before the first battery. However, as the selected battery charges up, a situation may occur in which the voltage of the selected battery being charged up by the power generator exceeds the voltage of the unselected battery. In such an instance, to prevent the current from flowing through the selected battery and into the unselected battery, the battery management controller **60** may control the second regulator **73** so that it is in a neutral mode to prevent any current from flowing between the two batteries or in a mode to ensure that only the selected battery is being charged.

Once the selected battery reaches a predetermined threshold such that it can be considered suitably charged, the process can proceed to step **906** in which the remaining battery is recharged. In this instance, the first regulator **72** may be controlled by the battery management controller **60** to only charge up the remaining controller. Alternatively, the first regulator **72** may be controlled to charge up both batteries but the second regulator **73** may be controlled such that the current will flow through the suitably charged battery and into the remaining battery, which may result in the suitably charged battery being “topped off.”

As an alternative to steps **905** and **906**, the user may select that both the batteries be charged at the same time. In this instance, the user may selected the charging rates upon which each battery should be charged. For example, if the user wishes to have both batteries charged at the same rate, the first and second regulators **72** and **73** may be controlled by the battery management controller **60** such that the same amount of current will flow into each battery, regardless of their respective states of charge. In addition, if the user wishes to have the batteries both be charged at different charging rates, the first and second regulators **72** and **73** may be controlled such that these rates can be accomplished by controlling the amount of current flow to each battery from the power generator and the amount of current flow from one battery to another. Thus, the battery management controller can control the first and/or second regulators to increase the amount of current flowing from the generator to one of the first and second batteries. Whether charged sequentially or concurrently, the power generator continues to recharge the batteries until they are both above a suitable respective threshold at which the recharging may cease or until the engine is stopped.

Referring back to step **904**, if there is no user input, the battery management controller may determine the charging rates of the first and second batteries based on a level of charge. In one example, one battery (such as the first battery used as a starter battery) may be selected to be charged first over the other if it falls below a certain threshold (step **908**), and then the remaining battery is charged after the selected battery is suitably charged (step **910**). Alternatively, both batteries may be charged at different charging rates based on the level of charge of each battery or other similar criteria. Whether charged sequentially or concurrently, the power generator continues to recharge the batteries until they are both above a suitable respective threshold at which the recharging may cease or until the engine is stopped.

FIG. **7** shows another embodiment of the power system **70'**. The configuration of the power system **70'** is the same as the configuration of FIG. **5** with the following exceptions. First, the first battery **40'** is not a starter battery but merely an auxiliary bank of batteries while the second battery **42'** is the main bank of batteries. In addition, the third regulator has been removed and the power from the second battery is directly channeled into the load **78**, such as the variable-speed HVAC system.

FIG. **8** shows another embodiment of the power system **70"**. The configuration of the power system **70"** is the same as the configuration of FIG. **5** with the following exceptions.

First, the first battery **40'** is not a starter battery but merely an auxiliary bank of batteries while the second battery **42'** is the main bank of batteries. In addition, the third regulator has been removed and the power from the first and second batteries is fed into the load **78** via the second regulator **73'**. The second regulator **73'** acts as a buck/boost DC-to-DC converter and as the boost regulator to the load **78**. The second regulator then permits current to flow between the first and second batteries as described in relation to the second regulator **73** in FIG. **5**, but also current can flow from the first and/or second battery to the load **78** based on the duty cycle of the switching transistor associated with the respective first battery, second battery, and load **78**.

FIG. **9** shows another embodiment of the power system **70'''**. The configuration of the power system **70'''** is the same as the configuration of FIG. **8** with the following exception. Instead of an electrical power generator **76** comprising a single alternator, the power generator comprises two charging devices **82** and **84**. Each charging device may be, for example, a wind turbine generator, a hydro turbine generator, a diesel generator, a gas turbine generator, an alternator, an AC source, one or more solar panels or any other power source. Both charging devices are connected to the first regulator **73**.

FIG. **10** shows another embodiment of the power system **70''''**. The configuration of the power system **70''''** is the same as the configuration of FIG. **8** with the following exceptions. First, instead of an electrical power generator **76** comprising a single alternator, the power generator comprises a motor/generator **86**. Second, the first regulator **72'** acts as a buck/boost DC-to-DC converter from the first and second batteries to the motor generator **86**. The first regulator then permits current to flow from the generator to the first and second batteries as described in relation to the first regulator **72** in FIG. **5**, but also current can flow from either or both the first and second batteries to the motor **86** based on the duty cycle of the switching transistor associated with the respective first battery, second battery, and motor/generator **86**. The battery management controller **60** may determine what mode the motor/generator is in, and whether power from the first and/or second batteries are required to power the motor/generator when in the motor mode.

In yet another embodiment of the power system, the configuration of the power system may be the same as the configuration of FIG. **5** with the following exception. One of the batteries is only charged by the other battery. For example, the first battery may be charged only by the second battery or the second battery may be only charged by the first battery. The configuration can be accomplished by removing the electrical connection from the first regulator to either one of the first and second battery. Alternatively, only one of the batteries is attached to the electric power generator **76** without even including the first regulator **72**. In yet another alternative, the configuration may be the same as FIG. **5** but that the first and second regulators **72** and **73** are always controlled by the battery management controller **60** so that one of the batteries is only charged by the other battery.

Because the first and second power source may be batteries, they may benefit from a periodic controlled overcharge, which is often referred to as an equalization charge. The equalization charge mixes up the electrolyte, which tends to stratify or separate into overlapping layers of acid and water and also helps remove some sulfate deposits. During an equalization charge, the battery is charged well after the point at which the battery would be normally considered to be fully-charged while avoiding excessive battery heating or electrolyte boil-off. For example, a battery voltage is allowed to rise to a high voltage (such as approximately 16, 17, or more volts for a 12 volt battery), where it is maintained for a length of time (for example, up to 7, 8, 9 or more hours) by adjusting of the charging current. Of course, it should be kept mind that if the first or second battery is a battery bank, the equalization charge would apply across the battery bank.

According to one embodiment of the present invention, the power generator **76** (such as an alternator) may be used to provide an elevated voltage for the equalization charge for one of the first (secondary) battery and the second (main) battery. For example, based on user input from the user interface **51**, the battery management controller **60** may be configured to control the power system **70** to conduct an equalization charge of one of the first (secondary) battery and the second (main) battery using the electrical generator to raise an output voltage to an increased value greater than the normal output voltage in order to conduct an equalization charge of one of the first (secondary) battery or the second (main) battery. To achieve this rise in output voltage, the battery management controller **60** may adjust the excitation of the electrical generator.

According to another embodiment of the present invention, one battery may be used to elevate the charge of the other battery so that the other battery undergoes an equalization charge. For example, based on user input from the user interface **51**, the battery management controller **60** may be configured to control the power system **70** to conduct an equalization charge of one of the first (secondary) battery and the second (main) battery using the other of the first (secondary) battery or the second (main) battery) by controlling the second regulator **72** such that a voltage difference is sufficiently created between the first and second batteries to cause a flow of current from one battery to the other such that the other battery undergoes an equalization charge.

Next, the HVAC component controller **50** will be described. The HVAC component controller **50** controls the components of the HVAC system **10**, and works in conjunction with the battery management controller **60**. The purpose of the HVAC component controller **50** is to: (1) communicate to the user via the user interface; (2) monitor safety functions and initiate appropriate responses; (3) maximize the operational efficiency of the HVAC system by optimizing the speed of the condenser and evaporator fans and the speed of the compressor motor according to ambient conditions and user preferences; (4) regulate the speed of the condenser fans to control the condenser temperature thereby obtaining the best compromise between increased fan motor power consumption and increased compressor motor power; (5) regulate the speed of the evaporator fan proportionate to the temperature differential between the user temperature set point and the actual ambient temperature; and (6) regulate the speed of the compressor motor to maintain the desired evaporator temperature.

The HVAC component controller **50** carries out its function by being operationally connected to the battery management controller **60**, the user interface **51** (which includes a display **310** and one or more inputs **312**), a plurality of sensors, and the operational components of the HVAC system as show in FIG. **11**. The plurality of sensor detects a variety of parameters including: the vehicle's interior ambient temperature detected by a temperature sensor **304**, the humidity of the vehicle's compartments by using a humidity sensor **307**, and noise and/or vibration from one or more noise or vibration sensors **308**.

As to the operational components of the HVAC system, the HVAC component controller **50** may run the motor **12** that drives the compressor **14**; the circulation blowers that blow the temperature-controlled air into one or more designated compartments (such as the vehicle compartment **23** and/or the sleeping compartment **27**); the heaters for the heating system (such as the air heaters **272** and **274** from FIG. **1** or the heater **180** from FIG. **2**); and the control doors (if applicable) for the regulation of the temperature. Additionally the HVAC component controller **50** may also switch any control valves to control the flow of refrigerants (such as the valves **28** and **29** from FIG. **1** or the valves **184** and **184** from FIG. **2**). In one embodiment, the motor **12** of the compressor **14** may be controlled by the HVAC component controller **50** using a closed loop proportional, integral, derivative (PID) control. Similarly, the HVAC component controller **50** may also control the fan speed of the circulation blowers **210** and **212** via a pulse width modulated (PWM) PID control loop that is independent of the control for the compressor.

In one embodiment, the HVAC component controller **50** may modulate the speed of the motor **12**, and thus may modulate the capacity of the compressor **14** driven by the motor **12**. The modulation of the compressor may range between an upper compressor capacity and a lower compressor capacity. The compressor capacity may vary depending on the compressor capacity required to maintain the evaporator **22** or **26** at the evaporator temperature T_E as commanded by the control logic circuit **66**.

In one exemplary embodiment of the present invention, the HVAC component controller **50** ("HCC") may work as described below with reference to FIG. **12**. The HVAC component controller **50** receives a signal from the user interface **51** to begin operation at step **702**. Commands are sent to the battery management controller **60** ("BMC") from the HVAC component controller **50** to supply power to the HVAC system **10** at step **704**. The user interface **51** is polled for the user preference settings, such as the mode of operation, the location of temperature control, and the desired set point temperature T_{sp}. Also the ambient temperature T_a is read from the temperature sensor **304** at step **706**.

If the user preference is for the "cooling" mode, the process is sent to step **708** where a command is issued to start all fans of the circulation blowers **210**, **212** and the motor **12** of the compressor **14** to a minimum speed. At step **710**, the compressor speed is then commanded to bring and hold the evaporator **22** to a predetermined evaporator temperature T_E if the vehicle compartment is being cooled or to bring and hold the evaporator **26** to a predetermined evaporator temperature T_E if the sleeping compartment is being cooled. At step **712**, the fans of the condenser **16** are commanded to bring and hold the condenser **16** to a predetermined condenser temperature T_C.

If the user preference is for the "heating" mode, a command from the HVAC component controller **50** is issued at step **714** to start the fans of the circulation blowers of the evaporator **22** or **26**. The electric heating element **270** or **274** is commanded at step **716** to a power level (via PWM control) proportionate to the fan speed of the circulation blowers of the evaporator **22** or **26**.

With the HVAC system **10** now running in either the heating or cooling mode, the battery management controller **60** is polled for an estimate of the run time based on the present power draw and stored energy available for use in step **718**. As step **720**, the estimated run time is compared to the desired run time which was programmed into the user settings by the user using the user interface **51**. The HVAC component controller factors the difference between the estimated and desired run times into planning the output of the HVAC system **10** to ensure that sufficient power is available for the duration of the heating or cooling period (also called the "run time plan"). Based on the run time plan, the HVAC component controller **50** may increase or decrease the average capacity of the HVAC system periodically throughout the cycle. In particular, if the amount of heating (steps **726** and **736**) or the amount of cooling (steps **726**, **728**, and **730**) would require too much power to be drawn from the power source (s), the highest capacity of the HVAC system **10** possible would be employed which would still allow the battery management controller to supply power through the entire operational period. The highest capacity possible may be obtained through a combination of settings which would offer the best efficiency for the prevailing conditions.

At step **722**, a variety of measurements are taken at step **722** so as to ensure that the HVAC system runs efficiently with its limited power supply. These measurements include the actual ambient temperature of the vehicle's interior T_a, the evaporator temperature T_E, and the condenser temperature T_C. At step **722**, temperature sensors on the evaporator measure the evaporator temperature T_E, temperature sensors on the condenser measure the condenser temperature T_C, sensors in the vehicle and/or sleeping compartments measure the ambient temperature T_a, and the user inputs the desired ambient temperature or the set point temperature T_{sp} via the user interface **51**.

For efficient operation of the HVAC components in either the cooling or heating mode, a calculation is made at step **724** in which a difference Δ between the ambient temperature T_a and the set point temperature T_{sp} is determined. Then, the circulation blowers at the evaporator **22** or **26** are commanded to a speed proportionate to the difference Δ at step **726**. The determination of an appropriate fan speed for the blowers at the evaporator based on a given Δ may be based on any one of a number of methods known in the art such as tabular formulations or computer models.

The air blown into the vehicle and/or sleeping compartments affects the ambient temperature of the compartment; thus with continued operation of the HVAC system, the difference (Δ) between the ambient temperature T_a and the set point temperature T_{sp} begins to decrease. As the ambient temperature T_a nears the set point temperature T_{sp} the HVAC component controller **50** reduces the fan speed of the circulation blowers at the evaporator **22** or **26** proportionately based on Δ, as seen in step **726**. If the system is in the cooling mode, the reduced air flow over the evaporator **22** or **26** causes the evaporator temperature T_E to fall. In response, the HVAC component controller **50** adjusts the speed of the motor **12** that drives the compressor **14** to maintain the desired evaporator temperature T_E at step **728**. Similarly, the changing capacity of the evaporator **22** or **26** also changes the temperature of the condenser T_C. Again, the HVAC component controller **50** adjusts the fan speed of the condenser **16** so as to maintain the desired condensing temperature T_C at step **730**. However, the settings for the circulation blowers, the compressor, and the condenser (which are set in steps **726**, **728**, and **730** respectively) are subject to the highest possible capacity of the HVAC system based on the run time plan. Thus, if too much power would be drawn by these components while running at the most efficient operation, the settings of these components would be adjusted so as to allow the system to run for the desired run time while operating as close as possible to the most efficient operation determined by Δ.

The process continues to step **732** where the HVAC component controller receives data from the battery management controller **60** about whether there is sufficient power being supplied. If there is sufficient power (the "YES" path), the process returns to step **718** and the process is repeated. If there is insufficient power (the "NO" path), the operation of the HVAC system is terminated at step **734**.

If the HVAC system is operating in heating mode rather than the cooling mode, the HVAC component controller **50** alters the PWM cycle of the resistive heating elements **270** or **274** to match the changing fan speed of the circulation blower at the evaporator **22** or **26**. In this way, the temperature of the discharged air remains constant. Thus, step **736** is carried out in FIG. **12** instead of steps **728** and **730**. Similar with the cooling operation, the settings for the circulation blowers and the heater (which are set in steps **726** and **736** respectively) are subject to the highest possible capacity of the HVAC system based on the run time plan. Thus, if too much power is being drawn by these components while running at the most efficient operation, the settings of these components may be adjusted so as to allow the system to run for the desired run time while operating as close as possible to the most efficient operation determined by Δ. For example, the settings of the circulation blowers may be lowered to a level that permits operation during the entire desired run time while still operating as close as possible to the settings for the most efficient operation based on A.

Other system parameters may be used to control the motor-driven compressor **14** and the circulation blowers **210** and **212**. For example, the HVAC component controller **50** may also monitor humidity of the vehicle's compartments by using a humidity sensor **307**. If the humidity of the compartments is above a predetermined threshold (which may be set by the vehicle occupant), the HVAC component controller **50** may control the compressor **14** to speed up (up to but not exceeding the upper compressor capacity) and the circulation blowers **210** and **210** to slow down.

Furthermore, one or more noise or vibration sensors **308** may be used to determine the level of noise or vibration of the HVAC system **10**. Once the signal is sent to the HVAC component controller **50**, the controller **50** determines whether there is a need to speed up or slow down the compressor and/or blower, and to control the compressor and/or blower accordingly.

The use of one or more system parameters, such as the evaporator temperature, the humidity, the exterior ambient temperature, the vehicle's interior temperature, etc. to control the compressor and blower capacities may be accomplished by monitoring the one or more system parameters and using a program in the HVAC component controller **50** that was compiled using, for example, a multivariate model known in the art.

Other system parameters may also be provided to the HVAC component controller **5**, which may allow the HVAC component controller **50** to detect faults within the HVAC system. For example, performance and safety functions are monitored and an appropriate response by the HVAC component controller **50** may be initiated, such as shutting down the system in the event of the overheating of the motor **12** of the compressor **14**.

FIG. **13** shows another embodiment of the HVAC system according to the present invention. The embodiment in FIG. **13** is similar to the embodiment of FIG. **1**; however, FIG. **13** shows how the HVAC system may be divided up into a split system **600** in which there is an exterior subsystem **602** and an interior subsystem **604**. The exterior subsystem **602** may comprise components that are located on the exterior area of the vehicle's cab. The interior subsystem **604** may comprise components that are located in the interior area of the vehicle's cab, wherein the interior area includes a driver compartment and a sleeper compartment. The driver compartment is at least partially segregated from the sleeper compartment. FIG. **13** shows an exterior subsystem **602** that comprises a motor **12**, a compressor **14**, a condenser **16**, and a first power source, which are located outside the cab of a large vehicle, such as a truck. In addition, the second power source and the electrical power generation system **44** may also be located on the exterior of the vehicle's cab as is conventional with large vehicles. The exterior subsystem is mounted to a location outside the interior area. For example, the exterior subsystem is mounted to a rear side of the interior area or is mounted underneath the interior area.

The interior subsystem is mounted within the interior area and is to be operably connected with the exterior subsystem. The interior subsystem may mounted in the sleeper compartment, such as underneath a bed in the sleeper compartment. The interior subsystem **604** may comprise the circulation blower **610**, the evaporator **622** and the HVAC component controller **50**, the battery management controller **60**, the display **310**, and the input device **312**, which are all located inside the cab of the vehicle. The temperature controlled air may be optionally channeled into ducts **672**, which may split into two or more ducts that may lead to different compartments or areas of the interior of the vehicle's cab. In one embodiment, the ducts **672** may be the vehicle's own ducting which is already installed in the vehicle cab. Additionally, the interior subsystem **604** may comprise the vehicle's already existing evaporator **622** and circulation blower **610**. In such a situation, the exterior subsystem **602** may be configured to be able to connect to a plurality of different evaporators, such as the vehicle's own evaporator. In addition, the exterior subsystem **602** may be configured to connect to a plurality of evaporators at one time, such as one evaporator for cooling/heating the driving compartment and one evaporator for cooling/heating the sleeping compartment.

In FIG. **13**, the refrigerant metering device is located exterior to the vehicle's cab as part of the exterior subsystem **602**, which allows the servicing of the metering device to be easier if it should fail. Alternatively, the refrigerant metering device **20** may be located in the interior of the cab as part of the interior subsystem **604**.

The interior and exterior subsystems may be connected to each other by a liquid phase cooler **1002**, as shown in FIG. **15**. The liquid phase cooler **1002** comprises an outer tube **1004** with two first connectors **1010** and an inner tube **1008** with two second connectors **1006**. The inner tube **1008** is placed within the outer tube **1004**. The tube may be made of any suitable material, such as plastic. Liquid refrigerant can be transferred within the inner tube **1008** or in the outer tube **1004** while gas refrigerant can be transferred in the other tube. The ends **1012** of the outer tube **1004** are sealed so that the fluid running between the inner wall of the outer tube and the outer wall of the inner tube does not leak. If liquid refrigerant is transferred between the inner wall of the outer tube and the outer wall of the inner tube, there is an additional benefit that insulation would not be needed. Furthermore, the boiling of liquid caused by the heating of the liquid by the sun is inhibited; thereby improving the efficiency of the cooling. Also, having one tube inside another would effectively be similar to having a single tube, which would be easier to attach to the back of a truck.

According to one embodiment, the exterior subsystem **602** further includes a quick connect inlet port **1014** and a quick connect outlet port **1016**. The interior subsystem **604** further includes a quick connect inlet port **1018** and a quick connect outlet port **1020**. The inner and outer tubes **1004** and **1008** are first and second quick connect lines, respectively, for operably connecting the exterior subsystem **602** and the interior subsystem **604**. The first quick connect line **1008** connects the quick connect inlet port **1014** of the exterior subsystem **602** and the quick connect outlet port **1020** of the interior subsystem **604**. The second quick connect line **1004** connects the quick connect inlet port **1018** of the interior subsystem **604** and the quick connect outlet port **1016** of the exterior subsystem **602**.

The quick connect inlet port **1014** and the quick connect outlet port **1016** of the exterior subsystem **602** and the quick connect inlet port **1018** and the quick connect outlet port **1020** of the interior subsystem **604** may be low loss quick connect ports. The first and second quick connect lines **1004** and **1008** may be low loss quick connect lines with low loss quick connectors **1006** and **1010**, as seen in FIG. **16**(*a*). For low loss quick lines, fluid is retained in the lines because of spring-loaded seals **1024** located in the connectors **1006** and **1010**. When the connectors **1006** and **1010** are attached to their respective mating ports **1014**, **1016**, **1018**, and **1020**, a plunger **1022** within the respective port depresses the spring loaded-seal **1024**, thus permitting fluid to flow through the connect lines. When the connectors and ports are disconnected, the plunger **1022** removes its pressing force from the spring-loaded seal **1024**, thus permitting the seal **1024** to spring back into its sealing position, which allows the fluid within the connect lines to be retained. Therefore, the low loss quick connect ports and the low loss quick connect lines **1004** and **1008** removably connect so that connection and disconnection can take place multiple times with low loss of refrigerant fluid.

Alternatively, the quick connect inlet port **1014** and the quick connect outlet port **1016** of the exterior subsystem **602** and the quick connect inlet port **1018** and the quick connect outlet port **1020** of the interior subsystem **604** may be one-time quick connect ports. The first and second quick connect lines **1004** and **1008** may be one-time quick connect lines with one-time quick connectors **1006** and **1010**, as seen in FIG. **16**(*b*). For one-time quick lines, fluid is retained in the lines because of membranes **1028** located in the connectors **1006** and **1010** providing a seal. When the connectors **1006** and **1010** are attached to their respective mating ports **1014**, **1016**, **1018**, and **1020**, a knife-edge **1026** punctures or ruptures the membrane **1028** within the respective port; thus permitting fluid to flow through the connect lines. The one-time quick connect ports and the low loss quick connect lines **1004** and **1008** will leak if the connectors are removed from their respective ports but provides the advantage of being smaller than the low-loss connectors.

Of course, other connectors and lines may be used for the connectors **1006** and **1010** and the connect lines **1004** and **1008**. For example, the connectors **1006** and **1010** may have flared fittings, sealed fittings, etc. Additionally, various combinations of fitting may be used. For example, both connectors **1010** and **1006** may be low-loss quick connectors, one-time quick connectors, or a combination thereof. According to one embodiment, one of the connectors **1010** and the connectors **1006** are low-loss connectors while the other of the connectors **1010** and the connectors **1006** are one-time quick connectors. According to another embodiment, the connectors **1006** and **1010** that lead to the evaporator **622** (i.e., connecting to the inlet port **1018** and the outlet port **1020** of the interior subsystem **604**) may be one-time quick connectors while the connectors **1006** and **1010** that lead to the condenser **16** (i.e., connecting to the inlet port **1014** and the outlet port **1016** of the exterior subsystem **602**) may be any suitable connector, such as one-time quick connectors, low-loss quick connectors, flared connectors, etc.

The split system **600** has several advantages. First, less interior space is taken up by the system because a substantial portion of the components are located exterior to the vehicle's cab. Additionally, the vehicle's existing ducts may be used so that no additional ducting is needed. Thus, the system may have an easier installation process, improved efficiency, and quieter operation.

The disclosed battery management controller and HVAC system may provide temperature control to a vehicle occupant for extended periods of time when the vehicle's engine is not running. In addition, the system ensures sufficient battery power to start the vehicle even when the HVAC system has been running for a period of time when the engine has been turned off. The battery management and HVAC systems may be used in large trucks, such as 18 wheelers, as well as any other type of vehicle.

During operation, the HVAC component controller **30** processes the user inputs to determine the operational mode of the HVAC system **10**. When either the heating or cooling mode of operation is selected and when the engine is turned on, the vehicle electrical power generation system is used to power the necessary components. For example, the heater and circulation blowers are turned on during the heating mode of operation while the compressor, circulation blowers, and pumps are turned on during the cooling mode of operation.

When the heating mode is operating when the engine is turned off, the HVAC component controller **50** commands a heater (such as the coolant heater **180** in FIG. **2** or the air heaters **270** and **274** in FIG. **1**) and the circulation blowers **210** and **212** to turn on. The HVAC component controller **50** also controls the speed of the circulation blowers **210** and **212** via a pulse width modulated (PWM) PID control loop in order to maintain the temperature of the driving and/or sleeping compartment at the interior set point temperature. With the various disclosed embodiments, the heating of the interior of the cab may be performed without relying on diesel fuel but may be run purely by battery power. Thus, the heating may be performed without relying on the vehicle's engine being turned on.

When the cooling mode of operation is used when the engine is turned off, the circulation blowers **210** and **212**, the compressor **14** and/or the pump **176** are turned on. The HVAC component controller **50** modulates the capacity of the compressor **14** and the circulation blowers **210** and **212** to maintain the temperature of the driving and/or sleeping compartment at the interior set point temperature via PID control.

In either the heating or cooling mode when the engine is turned off, if the voltage of the combination of the first and second power sources drops below a predetermined amount, the first and/or second power source is disconnected and the HVAC system is only powered by the remaining power source. Once the voltage of the remaining power source drops below another predetermined level, the battery management controller **60** may be configured to disconnect the remaining power source, thus shutting down the HVAC system **10**.

Upon start up of the vehicle, the alternator or other charging device may be used to charge up the first and second power sources (if they are batteries) so that they are fully charged. In one embodiment of the present invention, the battery management controller **60** may also be used to connect the first power source (such as an auxiliary battery or bank of auxiliary batteries) during the start up of the vehicle in the situation where the second power source (such as the starter battery or bank of batteries) is too weak to start the vehicle, such as in the case where the starter battery is weakened because of very low exterior ambient temperatures.

Furthermore, the HVAC system may be a split system with a substantial portion of the components exterior to the vehicle's cab such that less interior space is taken up by the HVAC system. Also, the vehicle's existing evaporator and/or ducting may be used with the HVAC system for an easier installation process, improved efficiency, and quieter operation.

Operation of the battery management controller will now be described in general with regard to FIG. **14**, which discloses a power generation system. FIG. **14** discloses a power generation system including a pair of power generators **101**, **102**. The generation system also includes main and auxiliary battery systems **131**, **132**. The power generators are connected to an AC power distribution bus **150** and the battery systems are connected to a DC power distribution bus **145**. Although AC and DC busses are shown, the power generation system may include a single DC bus. The power generation system includes AC load(s) **105** and DC load(s) **110**. As mentioned above, the loads may be supplied by a single DC distribution bus and individual inverters provided for each AC load. As shown in FIG. **14**, the power generation system may include an inverter **103** for converting AC to DC power. Alternatively, the system may include a motor/generator set for handling DC/AC or AC/DC power conversion.

As shown in FIG. **14**, the system includes AC power generators but, alternatively, a primary source of DC power may be provided. The power generators **101**, **102** may serve as a charge source for the battery systems **131**, **132**. For example, the power generators may include, for example, a wind turbine generator, a hydro turbine generator, a diesel generator, and a gas turbine generator, etc. The power generation system may include several power transfer units (PTUs) **120** controlled by a battery management or system controller **175**. The PTUs may simply be switches controlling the flow of power along their respective lines The PTUs may be mounted on one or more printed circuit boards and connected to the necessary wiring, electrical connections, and/or bus bars by any suitable means, such as wave soldering. The system may also include a power booster unit **127** (as described above).

The battery management controller **175** may include a control logic circuit and a memory, and may be connected to various system sensors. The battery management controller may be used to regulate the degree of discharge among the power sources so as to conform to the user preferences for battery change and use of various power sources. The memory **67** of the battery management controller may be used to log historical data and use the historical data to modify the operation of the system.

In one exemplary embodiment, the power generator **102** corresponds to a wind turbine generator used for battery charging. The controller **175** is configured to control the system so that the battery could either receive power from the generator **102** or provide power (i.e., motorize) the wind turbine. For example, during periods of no or little wind, the battery (or batteries) could be employed to power the generator **102** to drive the turbine blades and keep the blades spinning at a reasonable rate of speed. Maintaining the turbine rotating, would improve the efficiency of the wind turbine because when the turbine is always ready to make efficient use of each gust of wind to once again charge the batteries. There would be no losses associated with starting or speeding up the turbine.

The system FIG. **14** is an exemplary power generation system that may operate on similar principles to those described above with regard to FIGS. **1-8**. However, FIG. **14** demonstrates that the concepts herein have broad applicability to various power generation systems including multiple power sources including stored energy and rechargeable power sources.

Given the disclosure of the present invention, one versed in the art would appreciate that there may be other embodiments and modifications within the scope and spirit of the invention. Accordingly, all modifications attainable by one versed in the art from the present disclosure within the scope and spirit of the present invention are to be included as further embodiments of the present invention. The scope of the present invention is to be defined as set forth in the following claims.

What is claimed is:

1. A power system to be installed in a vehicle comprising:

a first battery having a first battery voltage and a second battery having a second battery voltage;

an electrical power generator configured to charge the first battery;

an electrical load powered by at least one of the first battery, the second battery or the electrical power generator;

a converter connected to both the first and second batteries and configured to operate in either a neutral mode or a first battery charging mode or a second battery charging mode, wherein the converter is configured to create a voltage difference between the first and second batteries in the charging modes; and

a battery management controller configured to monitor the first voltage of the first battery and the second voltage of the second battery and/or to monitor current flow to and from the first and second batteries, and wherein the controller controls operation of the converter to operate in either the neutral mode, the first battery charging mode or the second battery charging mode;

wherein in the second battery charging mode, the converter is configured to adjust the voltage difference between first battery and the second battery to cause current to flow from the first battery to the second battery to thereby charge the second battery.

2. The system of claim **1**, wherein the second battery is only charged by the first battery.

3. The system of claim **1**, further comprising a user interface configured to allow a vehicle occupant to select the operating mode of the converter.

4. The system of claim **1**, wherein the generator comprises an alternator configured to be driven by an engine of the vehicle.

5. The system of claim **4**, wherein the controller is configured to control excitation of the alternator in order to control alternator output voltage.

6. The system of claim **1**, wherein in the first battery charging mode, the converter is configured to adjust the voltage difference between the first battery and the second battery to cause current to flow from the second battery to the first battery to thereby charge the first battery.

7. The system of claim **1**, wherein in the neutral mode the converter is configured so that no current flows between the first and second batteries.

8. The system of claim **1**, wherein the electrical load comprises a system for heating a compartment of the vehicle.

9. The system of claim **1**, wherein the electrical load comprises a system for cooling a compartment of the vehicle.

10. The system of claim **1**, further comprising a current regulator connected to the generator and at least one of the first and second batteries, wherein the controller controls the current regulator to regulate the amount of current flowing from the generator to the at least one of the first and second batteries.

11. The system of claim **10**, wherein the controller is configured to control the current regulator and the converter to adjust relative charging rates of the first and second batteries.

12. The system of claim **1**, further comprising a boost converter connected to at least one of the first and second batteries and the load, wherein the boost converter raises the voltage being supplied to the load by the at least one of the first and second batteries.

13. The system of claim **12**, wherein the controller controls the boost converter to adjust the power being supplied to the load from the at least one of the first and second batteries.

14. The system of claim **1**, wherein one of the first and second batteries is connected to a vehicle starting system to provide power to start an engine of the vehicle.

15. A vehicle power system comprising:

an electrical generator driven by an engine of a vehicle,

a main battery connected to a secondary battery for supplying current an electrical load; and

a controller coupled to the main battery and the secondary battery; and wherein the controller is configured to adjust the system so that the main battery is charged by the secondary battery when a state of charge of the main battery is below a predetermined threshold even when a state of charge of the secondary battery is less than the state of charge of the main battery.

16. The system of claim **15**, further comprising a converter connected between the main and secondary batteries to control current flow between the main battery and the secondary battery.

17. The system of claim **16**, wherein the controller is configured to control the system to conduct an equalization charge of one of the main battery and secondary battery using the other of the main battery and the secondary battery.

18. The system of claim **15**, wherein the controller is configured to control the generator to raise an output voltage to an increased value greater than a normal output voltage in order to conduct an equalization charge of one of the main battery and the secondary battery.

19. The system of claim **18**, wherein the controller adjusts excitation of the generator in order to raise the output voltage.

20. The system of claim **18**, further comprising a current regulator connected to the generator and at least one of the main battery and the secondary battery, wherein the controller controls the current regulator to increase the amount of current flowing from the generator to the one of the main and secondary batteries being charged.

21. The system of claim **15**, wherein the main battery is used as a starter battery, and the determined threshold is a level of charge sufficient to start the engine of the vehicle.

22. The system of claim **21**, wherein the controller is configured to adjust the system so that the secondary battery charges the main battery to the predetermined level sufficient to start the engine of the vehicle even if the state of charge of the secondary battery is less than the state of charge of the main battery.

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